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Watertown Arsenal Laboratory
Report Number WAL 710/749
Project No. [illegible] B-3
Problem Nos. B-8.1 and B-8.2

30 October 1945

Review of Programs on Development of Body Armor Undertaken at Watertown Arsenal during World War II

OBJECT

To review the results of programs undertaken at this laboratory under Project B-3, during World War II.

SUMMARY

1. At the request of the Office, Chief of Ordnance, and in cooperation with other Ordnance agencies and various manufacturers, work has been conducted at this Arsenal since June, 1943, on the development of body armor.

2. Fragment-simulating projectiles were developed and an inspection technique involving the use of one of them against samples selected statistically has been incorporated into an acceptance specification which in several other ways was improved by suggestions from this laboratory.

3. Scores of materials (steels, non-ferrous metals, fabrics and plastic laminates) were tested and the following general observations can be made:

a. Austenitic steels and nickel alloys appear to be at their best in the "dead soft" condition.

b. Ferritic steels appear to be best "as-quenched", followed by a stress-relief treatment at very low temperature (about 300°F).

c. Aluminum alloys appear to be best when they have high tensile strengths, although, when the mechanism of penetration is such that eventual failure is in shear, high hardness may be detrimental.

d. The superiority of silk over other fabrics has not been evaluated but undoubtedly exists. Of the available fabrics, nylon is superior to others, and there is reason to believe that closely-woven, high-twist, multistrand fabrics are desirable.

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e. Doron stands head and shoulders above other plastic laminates which have been tested.

f. Tests were conducted which indicated that it is desirable to use as large plates as are consistent with flexibility in body armor assemblies. These indications have been recognized in the latest designs.

4. An opinion has been expressed herein as to the logical course of future experimental and development work on this project.

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I. INTRODUCTION:

During the winter of 1942/43, as a result of a comprehensive study of the occurrence of wounds to members of crews of combat bombing planes of the Eighth Air Force, it became apparent that a considerable portion of them could be attributed to so-called "low velocity missiles".

These deductions were brought to the attention of the Ordnance Department[1] early in 1943 and in reply[2] the Department furnished a critical analysis of the problem based on the data presented and recommended a program to develop desirable military characteristics.

Subsequently[3] the Commanding General of the Eighth Air Force presented a further analysis of causes of wounds to crewmen of bombing aircraft, as follows:

Flak	38%
20 mm. HE Shell Fragments	39%
Machine Gun Bullets	15%
Secondary Missiles (pieces of Aircraft)	8%

These data were based on 303 wounds of which 21% were due to low velocity missiles.

In this same communication were statements concerning protection in actual combat provided by armor made experimentally in England and a description of the armor used. The basic armoring components were overlapping plates of (Hadfield) manganese steel sewed in pockets of light fabric and backed by flax canvas. Four types of garments were in use designed to afford the various crewman protection without interfering with the performance of their ordinary duties.

It was urgently requested by the Commanding General of the Eighth Air Force that "production of this body armor be undertaken in the United States as soon as possible, and this Headquarters be informed of the action taken".

On 6 July 1943, the Air Force Materiel Command, which had initiated development contracts under this project, was directed[4] to turn over this project to the Ordnance Department and the same communication contained a request from the Army Air Forces for immediate procurement of over 25,000 armor assemblies of the four types used in England. It was required that 25% of that quantity be delivered at the port of embarkation by 5 August 1943. This latter stipulation set in motion some fast, furious and productive activities in the Ordnance Department.

Within 24 hours after receipt of this request, letters of intent were placed with three prime contractors. Tests of materials were initiated at the Bureau of Standards, at this Arsenal and at other Ordnance establishments. The advice of this laboratory was asked concerning factors to be controlled in the procurement of the steel components. Its opinion[5] as to the desirable chemistry, gauge, surface condition, heat treatment, physical properties and ballistic characteristics of the steel to be procured was sent to the Ordnance Office by air mail on 10 July 1943. On 12 July 1943, an improved design submitted by the Eighth Air Force was received from the Army Air Forces. The improved design was incorporated in new drawings and specifications which were issued under date of 15 July 1943, on which date official approval of procurement from experimental funds available to the Ordnance Department was given by the Ordnance Committee[6]. By 5 August a few more than the stipulated 25% had been produced, inspected, packed and delivered to the Port of Newark.

While crewmen of the Eighth Air Force had thus been furnished with the protection specifically requested, it was considered by the Army Air Forces[7] and by the Ordnance Department that improvements in design and in components were possible and recommendations[8] were initiated to assure such improvements as soon as the overload on Ordnance facilities occasioned by the urgency of initial procurement of these assemblies would be removed.

A representative of this laboratory took part in discussions at the Office, Chief of Ordnance, on 25 September 1943 during which the problems involved in improving body armor were outlined. As a result of these conversations this laboratory was requested[9] to undertake a three-fold program of development of improved body armor:

<u>a</u>. To devise a method of test procedure based in general on the information given in the letter of authorization which would be suitable for use in testing armor of current production and which would give an accurate picture of the quality of material then being supplied by various manufacturers;

<u>b</u>. To develop a steel for the plates which would be superior to that then in use, criteria of tests to be those devised under <u>a</u>.;

<u>c</u>. To determine the minimum thickness and optimum area for production of steel plates which would be definitely superior in ballistic characteristics to those then currently in use or to any which might be developed in accordance with <u>b</u>.

II. Development of Test Procedures

Since no experience in testing body armor was available at the outset of the program of procurement of armor assemblies, it was necessary to adopt a test procedure[10] which seemed to give some indication of the ability of the armor to resist perforation by low velocity missiles. This test involved subjecting the armor to impact with a cal. .45 ball projectile fired at service velocity (about 750 to 800 feet-per-second) and also to a round of statically detonated 20 mm. H.E. Shell and basing conclusions as to the acceptability of the material on the results. (This test is still being applied to the finished garment as a final check although specifications based on later and more competent data are now applied to the components prior to assembly.)

It was, however, contemplated that a special test would be devised which would more adequately reflect service conditions of attack and provide a basis for a more valid evaluation of a material's resistance to service perforation.

Such a test ideally would consist of actual fragmentation of service projectiles, and such tests were promptly suggested by this laboratory[11], but, because of the inherent variability of fragmentation, the number of rounds, necessary to give results from which any valid conclusions could be drawn discouraged the application of such methods and shifted emphasis in the direction of a test which would be simple, reproducible and measurable.

The necessity for developing a reproducible and measurable test introduced at the outset a certain handicap which will probably never be overcome completely. Studies of the behavior of fragments of high explosive shell after detonation, the results of which have been coming to light since the inception of this problem, have brought out the fact that perhaps no two fragments are identical nor is the pattern or rate of their successive orientations the same. Had the implications of these facts been fully realized when the procurement of body armor first became urgent it is doubted whether duplicability and measurability would have been insisted upon.

However, such was the requirement voiced at the time, and steps were undertaken which have resulted in fulfilling it in letter, if not in spirit.

Although reports from the Medical Department in the European Theater of Operations indicated that a majority of wounds were caused by low velocity missiles, the Ordnance Office in requesting development of a test procedure raised a question as to whether such wounds were actually caused by low velocity missiles of large mass or rather by relatively high velocity missiles of smaller mass.

It was suggested that a test procedure be developed which would include firing at low velocity with projectiles weighing about 150 grains and at higher velocities with projectiles weighing about 15 to 20 grains. It was stipulated that these projectiles should incorporate a sharp or cutting edge to simulate the irregular shape of a fragment. Further investigation indicated that the typical hardness of a fragment was between 220 and 240 BHN. Because of the wide variability of fragmentation there was found to be no typical shape for an H.E. fragment.

Accordingly there were soon developed[12] two cal. .30 projectiles weighing respectively 34 grains and 158 grains which had wedgelike noses and were capable of being fired from a standard cal. .30 Mann barrel reproducibly and measurably (Figures 1, 2, 3).

Thus, except for the weight of the smaller projectile, which was the minimum weight which could be made up in cal. .30 size, there now seemed to be available projectiles which would meet the requirements stipulated.

However, the velocities at which the heavier projectile perforated Hadfield manganese steel of the thickness used in body armor assemblies were so low that little or no conclusions could be based on results of such firings, and when, later in the program, materials other than steel commenced to be investigated the inevitable variability of adhesion of the sabot to the lighter projectile began to become a factor which influenced results and obscured the true performance of the armor.

The development[13] of a one-piece cal. .22 projectile of 17.4 grains with a chisel nose, capable of being fired from an ordinary cal. .22 rifle, (Figures 4, 5, 6), eliminated the problem of sabot adhesion and satisfied the weight requirement for a lighter projectile, and the greater percentage of work done at this arsenal in investigating various materials as prospective body armor components has been based on results of firings using this projectile. While a disappointing lack of correlation has resulted between the relative resistance of materials to perforation by this projectile and to perforation by actual fragments of statically detonated 20 mm. high explosive shell, due to the uniformly efficient manner* in which this projectile perforates material and the variable inefficiency with which an actual fragment, because of its random behavior in flight, perforates material, it is believed that the results of firings with this projectile may at least be used to advantage as a basis for evaluation of the control of

*These projectiles are fired from rifled barrels and present themselves to the target unyawed and at normal incidence.

quality being exercised by the supplier of armor material.

Since this lack of correlation became evident, evaluation of the relative merits of different materials has not been based on firings with this projectile and the full realization of the implications of the variability in size, shape and behavior of fragments has raised doubt as to the duplication of their effect in a single measurable and reproducible test. However, when more is known as to the relative resistance of materials to actual fragment attack, and programs are currently underway which will develop this information, it is considered that by reducing the efficiency with which the projectile presently perforates material (probably by causing it to attack obliquely) a reliable and economical substitute for the present prodigal procedure** may be developed.

Although this projectile is not currently used to evaluate the merits of different materials, it is used in a specification test suggested by this laboratory[14,15] to establish limits, for materials which have passed actual fragmentation tests, within which subsequent lots of the same material must fall as evidence of continued control of quality.

III. Investigation of Prospective Component Materials

In the correspondence initiating development of body armor at this laboratory it had been specifically requested that a steel superior to the type then in use be developed. As time went on, however, materials

**It is necessary to submit 40 samples 24" x 24" to actual fragment attack before a reliable estimate of the resistance of a material can be made.

other than steel have been investigated.

Accordingly, over a period of several months, a large variety of materials have been tested as possible components of body armor assemblies. Those fall rather naturally into four general classifications, - steels, non-ferrous metals, fabrics and laminates, - and will be discussed herein under these headings.

A. Steels[16] (Table References are made to Appendix A)

1. Hadfield Manganese Steel

a. Because of the urgency of the original procurement of body armor, Hadfield manganese steel, which was used in the "flak suits" first developed by the British and which has been used in both World Wars for helmets was stipulated as the basic armoring component. (It was contended that the role of body armor and helmets would be quite similar and a material proper for one application would be proper for the other application.)

b. Although it was felt that the original armoring component would provide adequate protection it was nevertheless considered desirable to improve the resistance of this element if possible.

c. There were readily apparent two avenues of approach to this object: (a) improvement of the resistance characteristics of Hadfield manganese steel; or (b) development of a steel of different chemical composition with better resistance characteristics.

d. Since there was available a considerable store of knowledge concerning Hadfield manganese steel, as a result of its use in helmets, its most resistant condition, according to existent criteria, was rather well defined and aside from a few corroborative studies of the effect of variations in hardness, microstructure and thickness[17-20], the efforts of this laboratory were, for the most part, expended in the development of inspection tests which would tend to eliminate material of inferior quality.

e. The results of various tests indicated that dead soft (Rockwell "B" about 90) Hadfield manganese steel free of decarburization and free of undissolved carbides represented the optimum condition of that material as regards resistance to perforation by fragment-simulating projectiles. There was considerable evidence, however, that much of the material then being used in body armor assemblies, while in the dead soft condition, suffered from the presence of decarburization or of undissolved carbides.

f. It was, therefore, deemed mandatory that a specification calculated to promote the acceptance of steel of good quality and the rejection of steel of inferior quality be introduced. The difference between steel of desirable quality and that of undesirable quality could most accurately be determined metallographically, but, because of the scarcity of personnel trained to conduct metallographic examinations, such a device was out of the question as an inspection tool. Tests indicated that a bend test[21] and a magnetic test[22] would reliably differentiate between acceptable and rejectable material. These tests could be applied and interpreted easily and quickly and were, therefore, ideal inspection tools. Consequently, such tests were introduced into a specification[23] which was applied to the material in the hands of the steel producer prior to shipment to the fabricator. The conscientious application of this specification assures a high probability of rejection of objectionable material.

g. Since it was considered that the capabilities of Hadfield manganese steel as a resistor had thus been fairly well exploited, attention was soon directed into the second avenue - development of a steel of different composition and superior resistance characteristics.

2. Other Steels

In cooperation with several steel producers and heat treaters, various steels in various conditions of heat treatment and in various gauges have been investigated.

In resistance to perforation by cal. .45 ball projectiles or by the fragment-simulating projectiles developed here, all these steels exhibited one common characteristic—inferiority to Hadfield manganese steel of equivalent gauge, when the gauge was less than .050".

When the gauge was greater than .050" some steels with high tensile strength have shown tendencies to equal and, perhaps, surpass Hadfield manganese steel in resisting perforation by these projectiles[24]. It is reasonable to expect such a tendency to assert itself as the gauge increases because such an increase imposes restrictions upon the ability of the Hadfield steel to deform prior to rupture, to which ability that material owes its superiority.

Since different materials tend to excel under test of different projectiles and since none of these steels has been given a significant fragmentation test, which, in the final analysis, should be our criterion of merit, no attempt will be made to list these materials in order of their ability to withstand expected service attack. Instead, a recital of the types tested, together with observations as to their behavior under attack of fragment-simulating projectiles follows:

a. Stainless Steel

Stainless steel was tested in three conditions of hardness induced by cold working[25]. In the "1/4 hard" (27 Rockwell "C") condition it exhibited much better overall resistance characteristics than in the "1/2 hard" (35 Rockwell "C") or "full hard" (45 Rockwell "C") conditions (Table II). Later tests (Table XVa) corroborated these findings, although the differences were less distinct, and indicated that when the nickel content of an 18-8 stainless steel was increased from 7% to 9.5% a drop in elongation occurred which was reflected in a drop in resistance to perforation[26].

b. SAE 4330 Steel

This steel, as heat-treated to a hardness of Rockwell "C" 54 to 56, exhibited resistance characteristics which were inferior to other ferritic steels (Table II)[27].

c. SAE 4340 Steel (Modified)

Samples of a modified SAE 4540 steel as normalized, oil quenched and tempered to 30, 40 and 50 Rockwell "C" were tested (Table VII). No appreciable difference in the perforation resistance of this steel at 30 Rockwell "C" and at 50 Rockwell "C" was observed[28]. The steel of intermediate hardness was somewhat inferior to these and all were substantially inferior to Hadfield manganese steel of equivalent weight. The quality of these samples was very poor, however, and directional failing due to nonmetallic stringers was frequent

d. Mn-Mo Steel

Several samples of manganese-molybdenum steels have been tested (Tables III, X, XI and XIII). The manganese content of these steels varied from 1.19% to 1.80% and the molybdenum content from .31% to

.51% while the carbon content hovered about .25%. Various heat treatments were employed: water quench; water quench, followed by tempering; oil quench; oil quench, followed by tempering; and austemper, with and without agitation. While no clean-cut decisions could be made because of the variability of samples, it appeared that samples as-quenched, with a stress-relief treatment at 300°F, were superior to samples in any other condition. Samples at the lower end of the .040" to .050" thickness range were substantially inferior to Hadfield manganese steel, but as the gauge approached the .050" mark samples of this steel showed equivalence to, or even slight superiority over, the austenitic steel of equivalent weight[29-32].

e. 0.70% Carbon Amola Steel

The resistance of a normalized, oil quenched sample of this material, tempered to 41/42 Rockwell "C" was inferior to that of a normalized, oil quenched sample tempered to 49/51 Rockwell "C" under impact of cal. .22 fragment-simulating projectiles and samples austempered to 49/50 Rockwell "C" and 53/54 Rockwell "C" were substantially superior to both although inferior to Hadfield manganese steel (Table IV). Under impact of cal. .45 ball projectiles, very little difference in resistance was demonstrated among the samples tested[33].

f. Silico-Manganese Spring Steel

A .042" sample of this steel, tempered to 49 Rockwell "C" exhibited resistance to perforation by cal. .22 fragment-simulating projectiles, 0-2, superior to that of an equivalent weight of Hadfield manganese steel, but under impact of the cal. .45 steel-jacketed ball projectile, the resistance of a similar sample was greatly inferior (Table XIII). The resistance of samples tempered to 40/45 Rockwell "C" was considerably inferior under both types of attack[34].

g. Si-Ni-Cr-Mo and Cr-Mo-V Steels

Samples of steels of these two types were given three different heat treatments: oil quench and temper; austemper; and normalize. The normalized samples (Rockwell "C" 49 and 51, respectively) afforded greatest resistance to perforation by both types of projectiles and both types appeared to offer equal protection (Table VIII)[35]. The quenched and tempered samples (Rockwell "C" 23 and 37, respectively) gave poorest results with little to choose between types. The austempered samples (both 46 Rockwell "C") produced intermediate results, with the Si-Ni-Cr-Mo steel exhibiting slightly superior resistance characteristics. All samples, however, were considerably inferior to the Hadfield type.

h. An Austenitic Steel

Samples of an austenitic steel of special analysis were tested "as annealed", and as "1/4 Hard", "1/2 Hard", and "Full Hard"[36]. The "as annealed" sample was superior to that of the hardened samples. Under impact of the cal. .22 fragment-simulator, the "1/4 Hard" sample appeared to be best. Neither approached the performance of Hadfield steel under similar conditions of attack (Table IX).

i. SAE X4130 Steel

Samples of this steel were tested "as rolled" and after an "oil quench and stress relief" treatment. "As rolled" the resistance of this steel was very poor (Table XIV). Heat treatment of a sample which was .048" thick increased its resistance to both types of projectile impact to the point that its performance duplicated that of Hadfield manganese steel of equivalent gauge[37].

j. NE-8630 Steel

Samples of this steel were tested "as rolled" and after the same heat treatment as was the SAE X4130 steel above (i). These samples were .042"/.043" thick and although heat-treatment increased the resistance of one sample to perforation by both projectiles, only its resistance to cal. .45 projectile perforation approached that of Hadfield steel (Table XIV)[38].

k. NE-8620 Steel

Samples of NE-8620 steel "as-quenched" and "as-tempered" at various temperatures were tested (Table XVI). The "as-quenched" samples again exhibited the best resistance characteristics. However, even "as-quenched", these samples did not compare with the NE-8650 samples above (j), which were heat treated here[39].

l. Ni-Mo Steel

Samples of a nickel-molybdenum steel in several conditions of heat treatment were tested (Table XVII)[40]. Under impact of the cal. .45 ball projectiles a normalized sample provided superior resistance. Under impact of cal. .22 fragment-simulating projectiles, the normalized sample and a sample stress relieved at 300°F. after quenching in oil were superior to samples which had received other heat treatment. None approached the performance of Hadfield manganese steel, however.

m. Si-Cr-Mo-Zr Steels

Samples of a Si-Cr-Mo-Zr steel in several conditions of heat treatment were tested (Table XVII). Under impact of cal. .45 ball projectiles, samples "as-quenched", "normalized", and "austempered at 675°F." were superior to others, and under impact of the cal. .22 fragment-simulator a sample stress-relieved at 300°F. after quenching and a sample "as-quenched" were greatly superior to other samples and equivalent to Hadfield manganese steel. All these samples were in the upper end of the thickness range, .040" to .050".

5. Summarization

Since the resistance of steels other than the Hadfield manganese type to perforation by actual fragments of high-explosive shell has not been definitely established, no authoritative estimate of their relative merits can be made.

However, if resistance to perforation by the cal. .22 fragment-simulating projectiles, 0-2, may be considered a criterion of a steel's resistance to perforation by actual fragments, the following observations are permissible:

a. For consistent high resistance to perforation, in thicknesses of .040" to .045", Hadfield manganese steel, free of decarburization and free of undissolved carbides, is outstanding;

b. Silico-manganese steel, tempered to a hardness of about 50 Rockwell "C" merits additional investigation and should be given an actual fragmentation test;

c. As the thickness nears the .050" gauge, ferritic steels appear to be able to match and sometimes better the performance of Hadfield manganese steel;

d. Among ferritic steels, greater resistance tends to attend higher hardness, unless inordinate brittleness accompanies the hardness;

e. Thus, "as-quenched" samples tend to be better than samples tempered to a lower hardness, but if the same hardness can be achieved by normalizing, or after a stress-relief treatment at about 500°F., the resulting product, with reduced brittleness, seems to afford slightly better protection.

f. Austenitic steels, in general, tend to offer greatest resistance in the "dead-soft" condition, as-annealed; this is not inconsistent with the observations made on ferritic steels, since in the case of the austenitic steels, increases in hardness above the "dead-soft" level must be induced by work-hardening which apparently introduces brittleness, even when only slightly applied.

B. Non-Ferrous Metals (Table References are made to Appendix B)

1. Aluminum Alloys[41]

Because of the promise shown by aluminum alloys as resistors of attack by projectiles which overmatch an equivalent weight of steel[42], it was considered that such materials might afford resistance to fragment attack superior to that of steel.

Accordingly, several aluminum alloys in various thicknesses have been tested. While, in comparison with samples of steel of equivalent weight, they have not afforded superior resistance to attack by fragment simulators because they have also been overmatched by such projectiles, as among themselves they have yielded some interesting information.

Under impact of cal. .45 steel-jacketed ball projectiles, a sample of 24S-RT[43] alloy (Table IV) exhibited better resistance than any other alloy tested. Following in order of their resistance to this type projectile were 75S-T[44,45] (Tables V, VII), R301-T[46] (Table II), 24S-T[47,48] (Tables VI, VII), 14S-W[49] (Table IV), and R301-W[50,51] (Tables I, IV) alloys.

Under impact of the cal. .22 fragment-simulator, T37, the same sample of 24S-RT showed greatest resistance. Following are 14S-W, R301-W, 24S-T, 75S-T and R301-T in that order.

Of the aluminum alloys so tested only the relative status of 24S-T and 75S-T duralumin has been reliably determined with respect to resistance to actual fragments of 20 mm. high explosive shell. There is some slight evidence of the standing of the R301-W alloy. On the basis of their ability to reduce the energy of attacking fragments, 75S-T duralumin is superior to 24S-T duralumin and the R301-W alloy appears to be somewhat inferior to the 24S-T alloy.

Referring to the relative resistance of these alloys to the test projectiles employed here it will be seen that some evidence of a positive correlation between the results of the cal. .45 tests and the results of actual fragmentation tests and a negative correlation between results of the latter tests and results of cal. .22 fragment-simulator tests.

2. Magnesium Alloy (Dowmetal)

In earlier work at this laboratory[52] some promise of resistance to attack by projectiles which overmatch equivalent weights of steel and aluminum alloys was shown by the magnesium alloy, Dowmetal.

Under attack of cal. .45 steel-jacketed ball projectiles and cal. .22 fragment-simulators, T37, however, this material offered so little resistance as to eliminate it from serious consideration[53].

3. Nickel Alloys (Appendix C)

A fairly exhaustive study of one type of Monel Metal and two types of high-nickel alloys in various conditions of hardness has been conducted[54].

The resistance of none of these samples to perforation by cal. .45 steel-jacketed ball projectiles or by cal. .22 fragment-simulating projectiles was comparable with an equivalent weight of Hadfield manganese steel. In general, the resistance of the softer specimens of a given alloy whose hardnesses had been developed by the same process tended to be superior to harder specimens of the same type. At a given hardness, however, specimens whose hardness had been developed by cold working, plus age hardening were greatly superior to those whose hardnesses had been realized from cold working alone. Of the three alloys tested the modified "Z" nickel alloy in its best condition was superior to the others. In its other condition, however, its resistance was not substantially different from that of any other alloy in similar conditions.

C. Fabrics (Table references are made to Appendix D)

Because of the necessity for employing a material allowing greater flexibility than metals to protect certain sections of the anatomy and still allow the wearer freedom of movement, it was decided to investigate the resistance characteristics of various fabrics[55].

Among fabrics silk has had a traditional role as a recognized armoring material. During World War I, although it was never used on an appreciable scale, the following findings were reported by William A. Taylor, a British govermmental armor specialist:

"The only material that gives materially better results than manganese steel is pure woven silk which, against shrapnel bullets up to a velocity of 900-1000 foot seconds, has a distinct advantage, weight for weight, over steel. For example, silk weighing

10.8 oz. per square foot is proof against shrapnel at 800 foot seconds, whereas steel to give the same resistance would weigh about 20 oz. (per square foot). The relative advantages and disadvantages of silk as compared with steel for body armor may be summarized as follows:

"Silk does not give nearly the same resistance as steel against high velocity or pointed projectiles (e.g. rifle bullets or bayonet thrusts) but on the other hand it does not deform a bullet when perforated. A bullet after passing through steel is deformed and would cause a very serious wound.

"Against low velocity blunt projectiles (e.g. shrapnel shell splinters, bomb fragments) up to a certain velocity silk is superior to steel, weight for weight.

"Silk sits better on the wearer than steel on account of its flexibility.

"For infantry, silk would probably be uncomfortably warm in summer and would require to be made water and vermin proof.

"Silk is more costly and difficulties of supply would be greater than with steel."[56]

Because of the disposition of the forces of the enemy in World War II, the use of silk by the Allies was out of the question and the resistance of silk to fragment attack was of purely academic interest and the only sample tested, while it was in a most inefficient form, showed excellent resistance characteristics when its form, webbing[57], was considered (Table IX).

While the superior resistance of silk is not characteristic of any other fabric, the general advantages and disadvantages set forth above by Mr. Taylor obtain for fabrics in general.

Of the fabrics feasible for use in World War II, nylon has shown outstanding ability to resist fragment perforation.

Unlike the resistance of metals, the relative resistance of fabrics has been similar under both extremes of projectile attack-- cal. .45 ball projectile attack and cal. .22 fragment-simulating projectile attack.

Thus we find sized nylon duck[58,59] (Tables I, II) and nylon parachute cloth[60] (Table IVa) superior to unsized nylon duck[61] (Table III) under both types of attack while nylon belting[62] (Table V) affords very poor resistance to both projectiles.

This latter poor showing of the belted nylon reflects the general inferiority of a fabric in belted form to the same fabric in loosely laminated form and accentuates the value of silk which, in this generally inefficient form compared favorably with nylon in its (nylon's) most efficient form.

Fiberglas, a material woven of threads whose fibers have phenomenal tensile strengths, did not exhibit such resistance as might be expected from the efficient utilization of this strength. It was somewhat inferior to the better forms of nylon but still showed respectable resistance characteristics[63,64] Tables VI, VIIa). In its least efficient form, belted[65] (Table VIII), it was, characteristically, greatly inferior to its more efficient forms.

An analysis of several types of Fiberglas showed a tendency for their resistance to reflect the characteristics of the yarn and the closeness of the texture, since those howing greatest resistance were closely woven and made of fine-fibred, multistranded, high-twist yarn while those affording least resistance were less closely woven of yarn with coarser fibers and a lower number of strands.

The resistance of cotton duck[66] (Table I) was spectacularly low and raises the question of consideration of other fabrics in such quasi-protective applications as hospital tents, sleeping bags, etc.

A protective fabric submitted by the Canadian government was tested[67] (Table V), but appeared to be inferior to the same weight of nylon in resistance to fragment-simulators.

Of all the fabrics investigated here, only sized nylon duck has been given a significant test by actual fragmentation. On the basis of this test it appears to be superior in resistance to any other material, metallic or non-metallic, so far investigated.

However, the resistance of a fabric depends, to a great extent, upon its ability to yield at the point of impact under the initial contact of the projectile, gradually increasing its resistance as it calls into play, centrifugally, the tensile strength of the threads. This necessitates clearance between the surface of impact and the surface of the target to be protected. In the practical application of a protective material to body armor this clearance may not be feasible.

D. Plastic Laminates (Table references are made to Appendix E)

The spectacular physical properties of plastic laminates and the ease with which they may be made to shape made them logical materials to investigate.

Of the several types tested here[68], Doron a laminate of Fiberglas impregnated with resins has shown consistent superiority over other types of laminates. These samples[69,70] (Table I), characteristically cause the impacting projectile to expend a great deal of its energy in delaminating the adherent surfaces and their resistance to attack by cal. .45 ball projectiles is superior to that of equivalent weights of steel.

Over a wide variation of temperature (-65°F. to +175°F.) this material maintained its resistance[71] (Table II).

Another type of Fiberglas laminate of different manufacture provided considerably less resistance[72,73] (Tables V, VI).

When cotton duck was used as the fabric component of a laminate the inferiority which was exhibited in the studies of plain fabrics reasserted itself[74] (Table V).

Laminates embodying rubber, either as an impregnant or as a cushion[75,76] (Tables III, IV) were consistently poor resistors.

"K" panels (sandwiches of an aluminum alloy between two pieces of Doron) showed intermediate resistance between that of the two components[77,78] (Tables VII, VIII). An increase in the proportion of the less resistant material (duralumin) or an increase in the more resistant Doron was reflected in the resistance of the combination.

Much greater resistance could be obtained, it is considered, if the Doron component were used entirely as a backing material instead of being split, front-and-back. The value of Doron on the face of the aluminum is dubious, whereas its presence at the rear of the target may conceivably add considerable resistance to the laminate.

Unfortunately, the spectacular superiority of Doron over other materials under impact of cal. .45 ball projectiles led to its overestimation in some quarters, as a fragment-resistant material. Much effort has been necessary to keep, from "going overboard" for this material, armor designers who have not had the benefit of the complete story of its resistance to actual fragments and to fragment-simulators and whose entire knowledge of the material has been carefully confined to its superiority under a unique test.

E. In General

While the development of no new material may be attributed solely to the work described above, because of the lack of a correlation between results of tests with fragment-simulating projectiles and results of actual fragmentation tests, it is considered that the best conditions of individual materials and perhaps, even classes of materials, have been well defined as a result of such tests.

Thus austenitic steels and nickel alloys appear to be at their best in the "dead soft" condition.

Ferritic steels appear to be best "as-quenched", followed by a stress-relief treatment at very low temperature (about 300°F.).

Aluminum alloys appear to be best when they have high tensile strengths, although, if the mechanism of penetration is such that eventual failure is in shear, high hardness may be detrimental.

The superiority of silk over other fabrics has not been evaluated but undoubtedly exists. Nylon, of the available fabrics, is superior to others, and there is reason to believe that closely woven, high twist, multistrand fabrics are desirable.

Doron undoubtedly stands head and shoulders above other plastic laminates tested.

IV. Component Plate Size and Disposition of Weight

Because of the emphasis on flexibility of the armor garment, the original model made use of very small (2") squares of steel as armoring components.

Early tests of complete garments at this arsenal indicated that these squares were much too small in that they could be turned about by the impacting projectile and penetration of the garment could be effected by by-passing the armoring component rather than penetrating it. Their small size also promoted the probability of their becoming secondary lethal fragments. It was urged that wherever the size of the armoring components could be increased without a disproportionate sacrifice of flexibility, steps should be undertaken to do so[79].

Meanwhile, these ideas were reiterated in consultation with designers of an infantryman's vest. These designers demonstrated that appreciable increase in plate size could be made without any sacrifice in flexibility[80].

These opinions have been corroborated in later models of flyers' protective armor in which much larger plates are currently employed.

When the resistance of a single sheet of a given material is compared with that of multiple sheets of the same material of equivalent cumulative weight, the resistance of the multiple sheets is generally found to be lower than that of the single sheet. This has a plausible explanation in that where penetration is effected by plastic deformation of the armor the resistance of a sheet near its surfaces is less than that near its interior and the more sheets involved, the more surfaces and the less resistance. Tests of a ferritic steel submitted for consideration as body armor[81] corroborate this general finding.

Tests on aluminum sheets, however, showed that the resistance of the single sheet was lower[82,83] (Tables III and VIII of Appendix B). This is not inconsistent with the general situation but, rather, distinguishable from it.

Penetration of aluminum alloys tested here has generally been effected by a pushing forward of the material in the path of the projectile. Failure in this case occurs from a shearing of the material after a small amount of plastic deformation. The entire resistance of the material is confined to the period of plastic deformation. By dividing the weight of such a material into several sheets the penetrating projectile is required to re-initiate this mechanism at each new surface. This results in an overall gain in resistance.

V. Specifications

Since one of the responsibilities of this laboratory is the translation of knowledge obtained concerning materials into requirements capable of incorporation into specification, much time has been expended in suiting information gained concerning the materials investigated in these programs to utilization in specification work.

Thus, the knowledge that decarburization and the presence of undissolved carbides in Hadfield manganese steel is detrimental to its ability to resist projectile perforation led to the development and recommendation of tests calculated to disclose the presence of these faults.

Similarly, realization of the extreme variability in the perforative characteristics of cal. .45 ball projectiles dictated recommendation of the procurement and reservation of standardized lots of these projectiles for use in testing armor[84-87].

Data accumulated during the conduct of extensive tests on Hadfield manganese steel furnished the basis of a recommendation of new requirements for resistance to penetration of prospective body armor materials[88]. This recommendation has as yet not been acted upon.

Recognition of the inadequacy of a single ballistic limit test in estimating the true resistance ability of a lot of steel gave rise to the recommendation of a ballistic test based upon considerations of the laws of probability[89]. This recommendation has not as yet been embodied into the specification.

Since it became apparent that a given material may be satisfactory with respect to resistance to actual fragments and yet, in comparison with other materials be very inferior in resistance to attack by fragment-simulating projectiles, considerable care has been taken by this Laboratory to define the use of the fragment-simulator as an inspection tool.

Thus, it would be gravely in error to set a standard of resistance to perforation by such a projectile which all materials would be required to meet. Yet it is desirable that a substitute for the prodigal procedure of the actual fragmentation test be available for lot to lot inspection.

The following procedure suggested by this laboratory represents a logical resolution of the problem:

<u>a</u>. A new material must prove its sufficiency by exceeding in resistance to perforation by actual fragments a standard which has been based on a reliably large number of tests of various materials.

<u>b</u>. The samples upon which the sufficiency of the material has been established are subsequently subjected to ballistic limit

determinations with the fragment-simulator.

c. A statistical analysis of these determinations is then made and on the basis of that analysis control limits are established within which average ballistic limit determinations of samples of subsequent lots are required to fall.

d. Failure of the average ballistic limit determinations of samples of a lot to fall within the control limits casts suspicion upon control of the process and action is taken based upon the general principles of quality control by statistical methods.

Such a procedure eliminates arbitrary discrimination against any material since each material sets its own level of performance and may logically be required to continue at that level.

As more information concerning the important properties of materials in resisting fragment perforation become known, the adequacy of specifications may be expected to improve.

VI. Work in Prospect

While considerable knowledge concerning body armor materials and design has been gathered since the inception of this program, the surface of the problem has only begun to be scratched. A well conceived and well executed program of research may conceivably develop a wealth of information in the next few years.

Such a program should logically embrace the following general considerations:

a. A test as closely reproducing service conditions as possible must be developed. (The present fragmentation of 20 mm. H.E. projectiles reproduces very well the conditions of attack against bomber personnel, but its application to other service conditions is questionable.)

b. Many different materials, varying in physical properties, must be subjected to such a test.

c. The results of these tests must be carefully analyzed for the detection of that physical characteristic or that combination of physical characteristics which affects the ability of materials to resist perforation.

d. A ballistic or a non-ballistic test capable of discriminating between materials which possess the proper amount of that characteristic and those which do not must be developed.

e. Methods of developing in a material the proper balance of desirable characteristics must be worked out.

f. Realistic evaluation of the undesirable characteristics such as bulk, rigidity and deformability, which sometimes must be accepted along with the desirable characteristic must be made.

The foundations for such a program are being poured currently. For body armor to protect against the spray of fragments of 20 mm. H.E. projectiles detonating upon contact with the "skin" of bombers, the present 20 mm. H.E. fragmentation test is an adequate reproduction of service attack. Several different materials are scheduled to be subjected to this test. Analysis of the results of such tests may disclose the critical physical characteristic which enhances resistance to perforation. The present test with the fragment-simulator may be capable of adaptation to disclose variations in this critical characteristic or a non-ballistic test may be devised.

If peacetime research in body armor is contemplated some such orderly procedure must be adopted. All phases of such a program, except the realistic duplication of service attack by high-explosive projectiles can quite adequately be performed by this laboratory.

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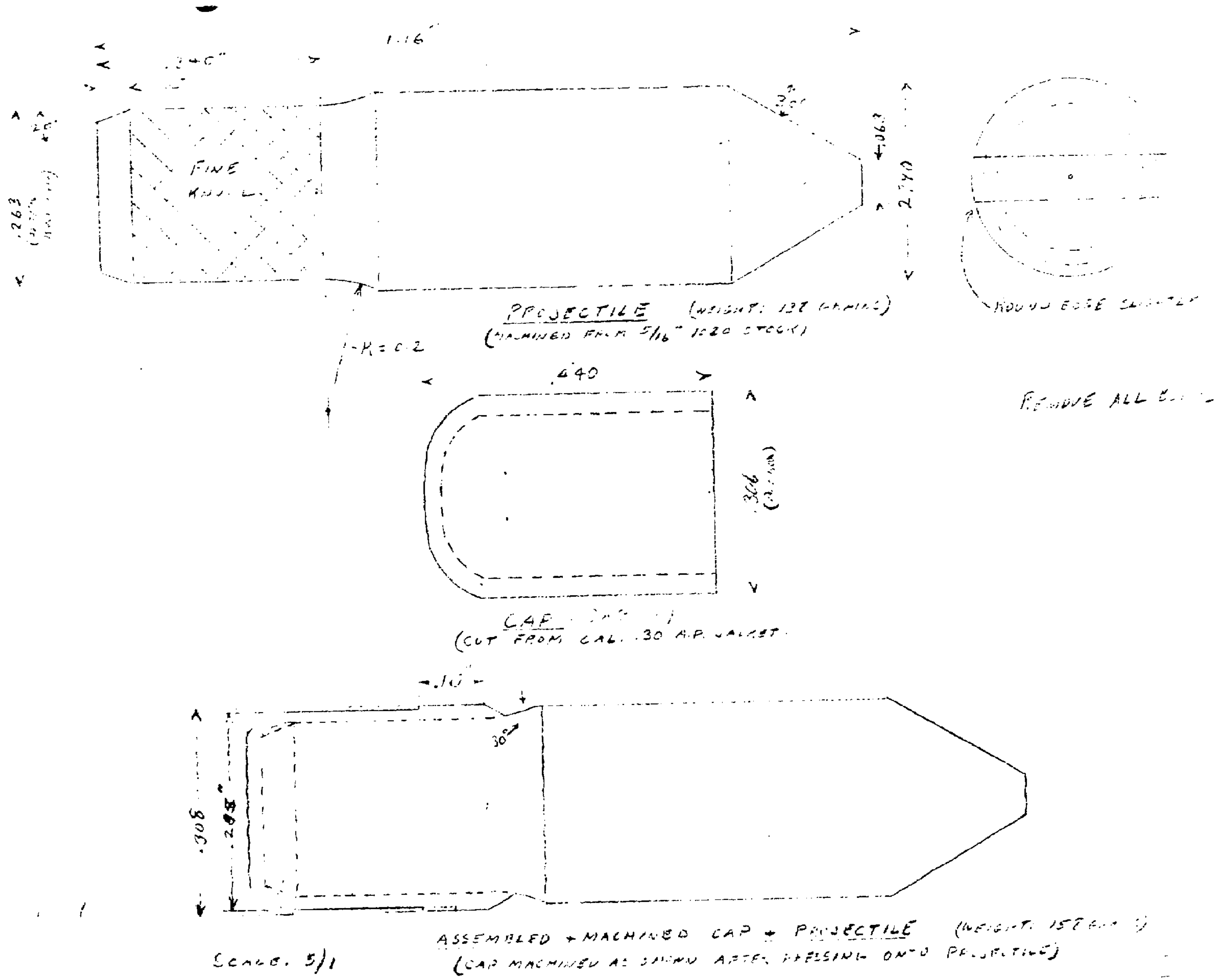

1.16"
FINE
.263
R = 0.2
.063
.290
30°
PROJECTILE (WEIGHT: 127 GRAINS)
(MACHINED FROM 5/16" 1020 STOCK)
ROUND EDGE SLIGHTLY
REMOVE ALL
.440
.306
CAP
(CUT FROM CAL. .30 A.P. JACKET
.10
30°
.308
.288"
ASSEMBLED + MACHINED CAP + PROJECTILE
(CAP MACHINED AS SHOWN AFTER PRESSING ONTO PROJECTILE)
SCALE: 5/1

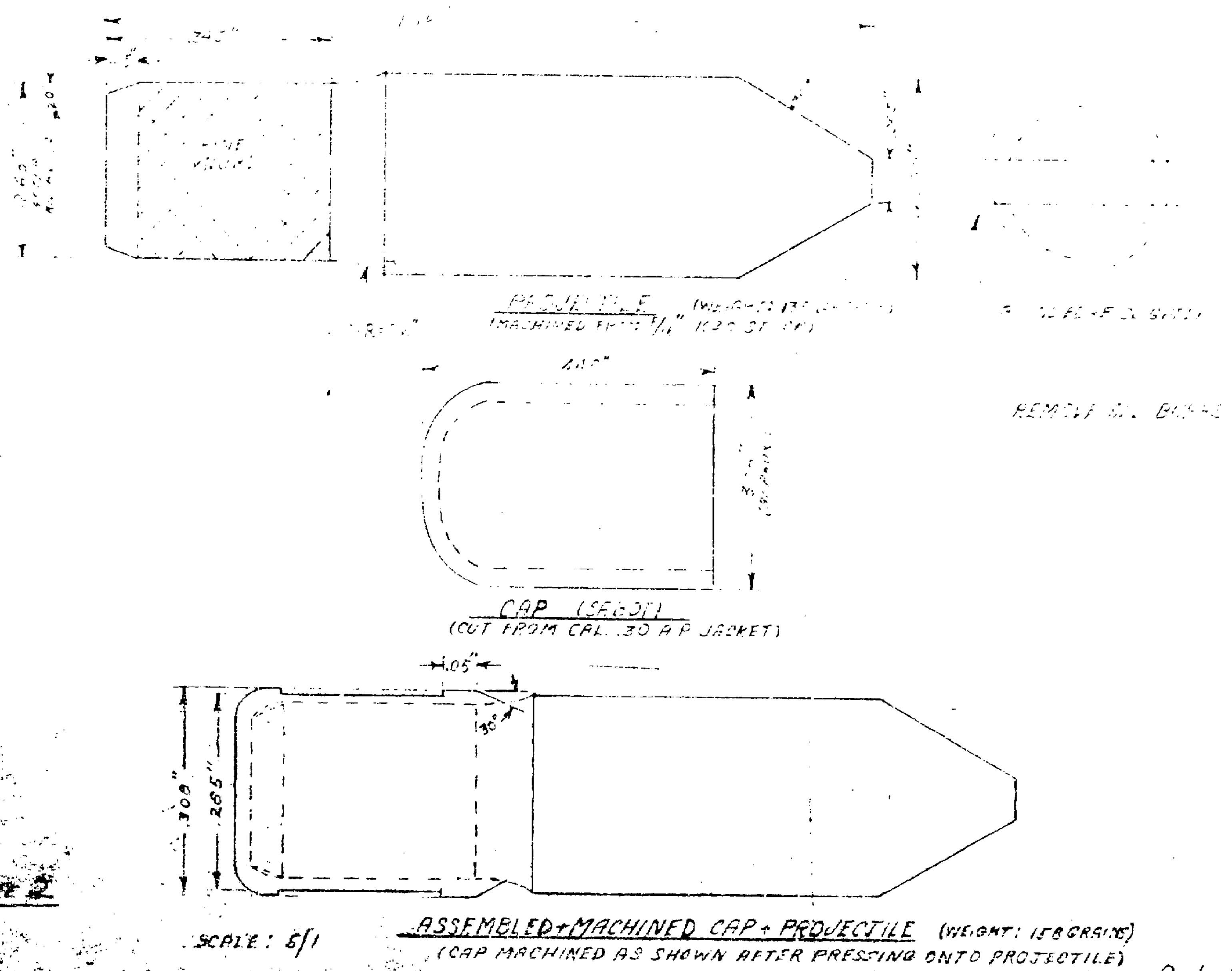
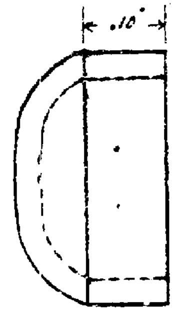


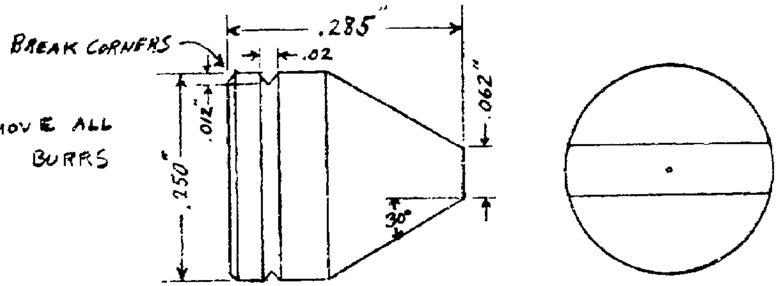
FIGURE 2

SCALE: 5/1

G-1-A

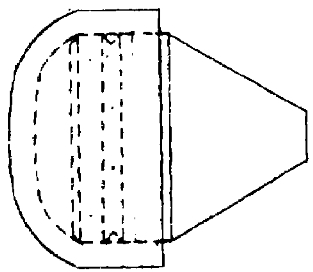


CAP (SABOT)
(CUT FROM CAL. .30 A.P. JACKET)
WEIGHT: 10.2 GRAINS



PROJECTILE
(MACHINED FROM .250" DRILL ROD)
WEIGHT: 24.4 GRAINS

SCALE: 5/1



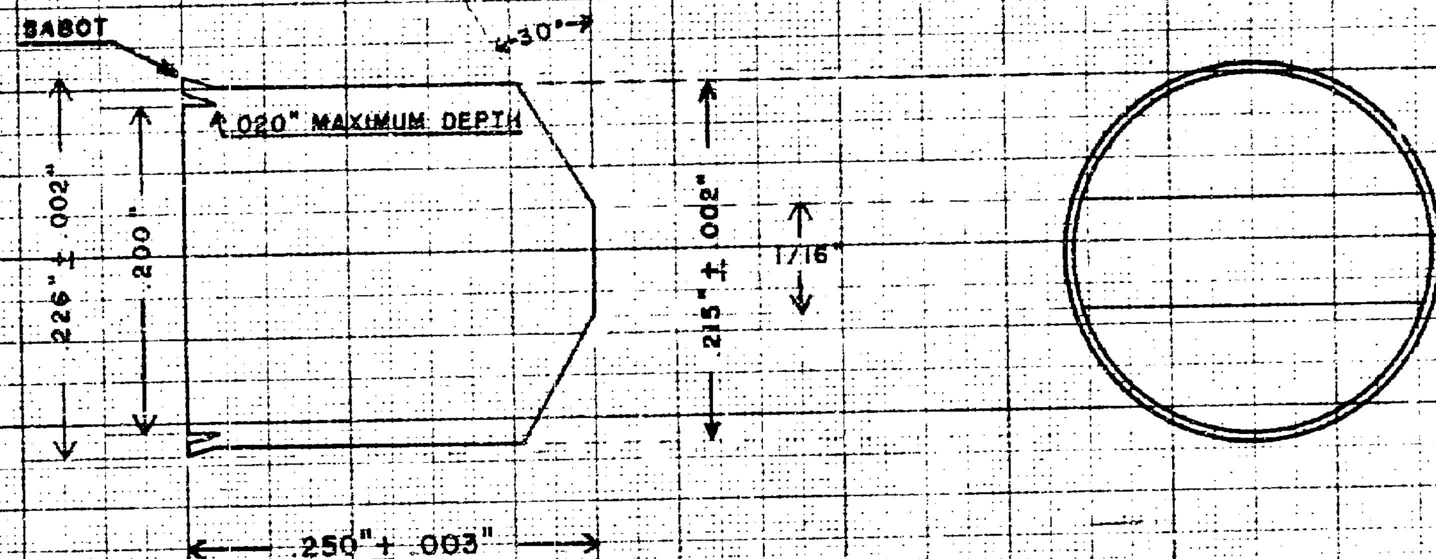
ASSEMBLED CAP + PROJECTILE
(ROUNDED BASE OF CAP MAY BE FLATTENED IN PRESSING ONTO PROJECTILE)
WEIGHT: 34.6 GRAINS

FIGURE 3

G-1-S

CAL. 22 FRAGMENT-SIMULATING PROJECTILE G-2

ROCKWELL "C" 20-25



WEIGHT - 17 GRAINS

WA JFS 1/6/44

FIGURE 4

TOOL FOR FORMING SABOT ON CAL.22 FRAGMENT-SIMULATING PROJECTILE G-2

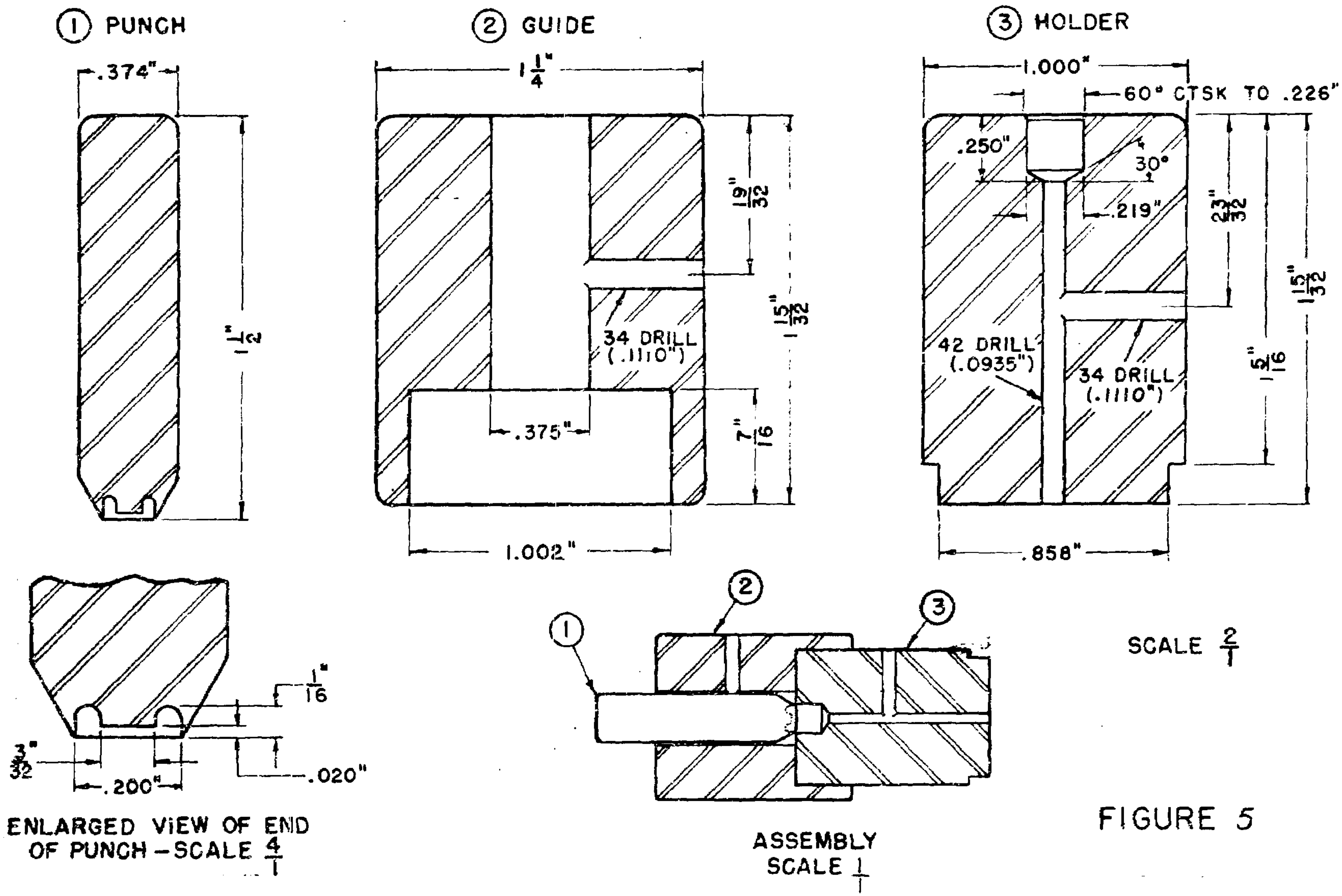
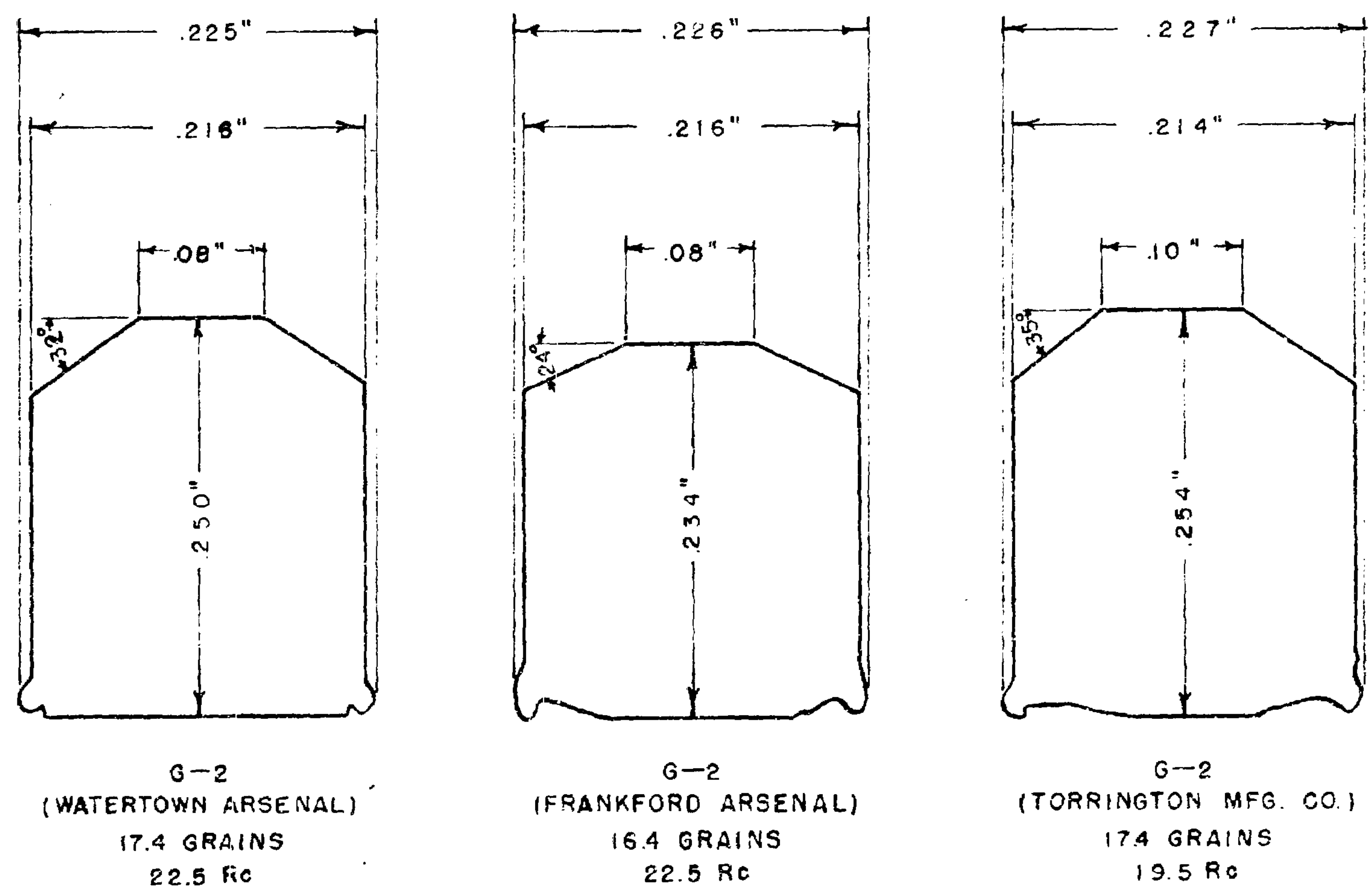


FIGURE 5



COMPARISON OF G-2 PROJECTILES OF VARIOUS MANUFACTURE
(DRAWINGS ARE NOT TO SCALE)

FIGURE 6

APPENDIX A

STEELS

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16. Watertown Arsenal Laboratory Memorandum Report No. WAL 710/632. "Effect of Hardness on Resistance of Thin-Gauge (.040" to .044") Hadfield Manganese Steel to Perforation by Fragment-Simulating Projectiles." J. F. Sullivan. 17 May 1944.

17. Watertown Arsenal Laboratory Memorandum Report No. WAL 710/712. "Resistance of Various Thicknesses of Hadfield Manganese Steel to Perforation by Various Projectiles." J. F. Sullivan. 5 January 1945.

18. Watertown Arsenal Laboratory Memorandum Report No. WAL 710/738. "Resistance of Hadfield Manganese Steel in Form of Helmet, M1, to Perforation by Fragment-Simulator, G-2." J. F. Sullivan. 26 April 1945.

19. Watertown Arsenal Laboratory Memorandum Report No. WAL 710/615. "Ballistic Characteristics of Four Types of Light-Gauge (.044" to .051") Steels Submitted by Republic Steel Corporation." J. F. Sullivan. 21 April 1944.

20. Watertown Arsenal Laboratory Memorandum Report No. WAL 710/693. "Resistance of Variously Chemically Balanced 18-8 Stainless Steels in Various Conditions of Hardness to Perforation by Flak-Simulating Projectiles." J. F. Sullivan. 18 September 1944.

21. See Reference 19.

22. Watertown Arsenal Laboratory Memorandum Report No. WAL 710/633. "Effect of Hardness on Resistance of a Thin-Gauge (.039" to .042") Modified SAE 4340 Steel to Perforation by Fragment-Simulating Projectiles." J. F. Sullivan. 17 May 1944.

23. Watertown Arsenal Laboratory Memorandum Report No. WAL 710/617. "Resistance of a Light Gauge Mn-Mo Type Steel to Perforation by Standard Cal. .45 Ball Ammunition and by Fragment-Simulating Cal. .22 Projectiles, G-2." J. F. Sullivan. 24 April 1944.

24. Watertown Arsenal Laboratory Memorandum Report No. WAL 710/648. "Resistance of a Light-Gauge (.039" to .051") Mn-Mo Steel, As Variously Heat Treated, to Perforation by Small Arms Projectiles." J. F. Sullivan. 3 June 1944.

25. Watertown Arsenal Laboratory Memorandum Report No. WAL 710/654. "Resistance of Light-Gauge (.040" to .042") .25% Mn-Mo Steel to Perforation by Fragment-Simulating Projectiles." J. F. Sullivan. 9 June 1944.

26. Watertown Arsenal Laboratory Memorandum Report No. WAL 710/668. "Resistance of Austempered Mn-Mo Steel to Perforation by Cal. .45 Steel-Jacketed Ball Projectiles." J. F. Sullivan. 18 September 1944.

REFERENCES (Cont'd)

27. Watertown Arsenal Laboratory Memorandum Report No. WAL 710/619. "Resistance of Light-Gauge (.041" to .046") Samples of 0.70% Carbon Amola Steel to Perforation by Fragment-Simulating Projectiles." J. F. Sullivan. 17 May 1944.

28. Watertown Arsenal Laboratory Memorandum Report No. WAL 710/667. "Resistance of Silico-Manganese Spring Steel to Perforation by Fragment-Simulating Projectiles." J. F. Sullivan. 1 July 1944.

29. Watertown Arsenal Laboratory Memorandum Report No. WAL710/634. "Resistance of Light-Gauge Si-Ni-Cr-Mo and Cr-Mo-V Steels to Perforation by Fragment-Simulating Projectiles." J. F. Sullivan. 18 May 1944.

30. Watertown Arsenal Laboratory Memorandum Report No. WAL 710/638. "Resistance of a Light-Gauge (.042" to .046") Austenitic Steel at Various Degrees of Hardness to Perforation by Fragment-Simulating Projectiles." J. F. Sullivan. 10 June 1944.

31. Watertown Arsenal Laboratory Memorandum Report No. WAL 710/672. "Comparative Resistance of Light-Gauge (.045") X4130 Steel and 8630 Steel, As-Rolled, and After Heat Treatment, to Perforation by Flak-Simulating Projectiles." J. F. Sullivan. 18 September 1944.

32. See Reference 31.

33. Watertown Arsenal Laboratory Memorandum Report No. WAL 710/697. "Resistance of NE8620 Steel in Various Conditions of Hardness to Perforation by Flak-Simulating Projectiles." J. F. Sullivan. 16 September 1944.

34. Watertown Arsenal Laboratory Memorandum Report No. WAL 710/702. "Resistance of Variously Heat-Treated Samples of Ni-Mo and Si-Cr-Mo-Zr Steels to Perforation by Fragment-Simulating Projectiles." J. F. Sullivan. 21 October 1944.

35. See Reference 34.

APPENDIX A

TABLE I

(Reference - Report No. WAL 710/568)

Ballistic Limits of Various Samples of Steels with Different Projectiles

and at Different Temperatures - Fired at Watertown Arsenal, 1 to 6 December 1943

Identi-fication	Dimensions (Inches)	Gauge (Inches)	Hardness	Type	Ballistic Limits (Projectile or Piece Thereof Thru) Cal. .45 (+50°F.)	Cal. .45 (-60°F.)	G-1-S (+65°F.)	G-1-A (+65°F.)
C	12x12	.048	75 Rb	Ferritic Steel	< 745	< 745	< 890	425
D	-	.048	23 Rc	Ferritic Steel	820	-	< 870	453
B	-	.048	35 Rc	Ferritic Steel	940	995	< 880	413
F	-	.043	88 Rb	Hadfield Steel	1117	-	995	545
K	-	.043	30 Rc	Hadfield Steel	848	-	943	418
A	-	.046	40 Rc	Hadfield Steel	898	Cracked	995	< 415
A-62	-	.044	92 Rb	Hadfield Steel	1131	1175	1175	501
G-5	Helmet	.040	50 Rc	Hadfield Steel	-	-	< 920	-
G-3	-	.040	90 Rb	Hadfield Steel	-	-	985	-
H-5	-	.040	50 Rc	Hadfield Steel	-	-	< 920	-
H-2	-	.040	90 Rb	Hadfield Steel	-	-	1010	-

APPENDIX A

TABLE II

(Reference - Report No. WAL 710/615)

Summary of Ballistic Tests Conducted at Watertown Arsenal on
Four Types of Steels Submitted by Republic Steel Corporation

Sample	Gauge	Ballistic Limit (F/S) G-2 (Cal. .22, 17 Grains)	Ballistic Limit (F/S) Standard Cal. .45 Ball*
1/4 Hard Stainless (Rockwell C-27)	.051"	1675	912
1/2 Hard Stainless (Rockwell C-33)	.048"	1173	646
Full Hard Stainless (Rockwell C-45)	.044"	1118	658
SAE 4330 (Rockwell C-36)	.048"	1553	698
SAE 4330 (Rockwell C-34)	.050"	1545	665
Hadfield Manganese (Average)	.050"	1750	1000

*Steel-jacketed.

APPENDIX A

TABLE III

(Reference - Report No. WAL 710/617)

Summary of Ballistic Tests Conducted at Watertown Arsenal on

Samples of a Mn-Mo Type Steel Submitted by

Jones and Laughlin Steel Corporation and Breeze Corporations, Inc.

Sample	Gauge	Chemical Composition C	Mn	Si	S	P	Mo	Tempering Temp. (°F.) 1 hour	Hardness Rockwell "C"	Ballistic Limit F/S 0-2[1]	Cal. .45[2]
GU-1	.028"	.23	1.19	.19	.020	.017	.33	As quenched	35	880	—
GU-2	.031"	.23	1.19	.19	.020	.017	.33	600°	29	775	—
GU-3	.030"	.23	1.19	.19	.020	.017	.33	700°	26	785	—
GU-4	.030"	.23	1.19	.19	.020	.017	.33	800°	18	750	333
GT-9	.039"	.24	1.50	.20	.016	.018	.31	As quenched	41	1375	699
GT-10	.040"	.24	1.50	.20	.016	.018	.31	600°	35	1105	494
GT-11	.038"	.24	1.50	.20	.016	.018	.31	700°	34	1050	less than 409
GT-12	.038"	.24	1.50	.20	.016	.018	.31	800°	33	1055	459
GT-1	.049"	.24	1.50	.20	.016	.018	.31	As quenched	35	1913	1027
GT-2	.048"	.24	1.50	.20	.016	.018	.31	600°(?)	29	1775	874
GT-3	.050"	.24	1.50	.20	.016	.018	.31	700°(?)	37	1920	1042
GT-4	.054"	.24	1.50	.20	.016	.018	.31	800°(?)	31	1823	817
All plates above were quenched in oil at 1250°F. from twenty minute re-heat at 1600°F.											
Hadfield Manganese Steel (Average)	.040"	—	—	—	—	—	—	—	—	1600	900
Hadfield Manganese Steel (Average)	.050"	—	—	—	—	—	—	—	—	1750	1000

1. Cal. .22 (17 grains) 2. Standard cal. .45 ball ammunition (steel jacketed) 230 grains.

APPENDIX A

TABLE IV

(Reference - Report No. WAL 710/619)

Summary of Ballistic Tests Conducted at Watertown Arsenal on Light Gauge (.041" to .046") Samples of 0.70% Carbon Amola Steel Submitted by Carnegie-Illinois Steel Corporation

Nominal Chemical Composition

C	Mn	P	S	Si	Mo
.60/.70	.70/.90	.040 max.	.040 max.	.20/.35	.20/.30

Sample	Gauge	Hardness	Ballistic Limit (F/S) G-2[1]	Cal. .45[2]
Item 9				
Normalized, oil	.039"	41 Rc	1053	--
quenched and tempered.	.039"	42 Rc	--	514
Item 10				
Normalized, oil	.040"	49 Rc	1057	--
quenched and tempered.	.039"	51 Rc	--	615
Item 11-A	.044"	50 Rc	--	830
Austempered	.046"	49 Rc	1165	--
Item 11-B	.041"	53 Rc	1020	--
Austempered	.041"	54 Rc	--	827
For Comparison:				
Hadfield	.040"	88 Rb	1600	900
Manganese Steel	.045"	88 Rb	1675	950

1. Cal. .22 (17 grains)

2. Standard cal. .45 ball ammunition (steel jacketed) 230 grains.

APPENDIX A

TABLE V

(Reference - Report No. WAL 710/630)

Summary of Comparative Ballistic Tests of Single Thin Gauge (.050") Steel Sheets and Multi-Layered Assemblies of the Same Aggregate Weight

Sample	Ballistic Limit (F/S) Caliber .45[1]	G-22[2]
one .050" sheet	867 (partial penetration)	1574
two .025" sheets	-	1290
five .010" sheets	849 (complete penetration)	935

1. Standard caliber .45 ball ammunition (230 grains - steel jacketed).

2. Caliber .22 fragment-simulating projectile - 17 grains.

APPENDIX A

TABLE VI

(Reference - Report No. WAL 710/632)

Summary of Ballistic Tests Conducted at Watertown Arsenal on

Hadfield Manganese Steel, As Annealed and After Hardening by Cold Reduction

Sample	Gauge	Hardness	Ballistic Limit (F/S) G-1-A[1]	G-1-S[2]	G-2[3]	Cal. .45[4]
As Annealed	.044"	89 Rb	--	--	--	949
		88 Rb	--	1144	--	--
		87 Rb	485	1083	1570	--
Half-Hard (Nominal)	.040"	38 Rc	--	814	1232	--
		39 Rc	345	-	--	613
3/4 Hard (Nominal)	.040"	37 Rc	--	-	--	625
		38 Rc	--	-	1184	--
Corrected for thickness difference:						
As Annealed	.040"	--	(factor undetermined)		1510[5]	909[6]

1. caliber .30 fragment-simulating projectile (150 grains)
2. caliber .30 fragment-simulating projectile (34 grains)
3. caliber .22 fragment-simulating projectile (17 grains)
4. caliber .45 ball ammunition (230 grains - steel jacketed)
5. 1570 - (4x15) = 1510
6. 949 - (4x10) = 909

APPENDIX A

TABLE VII

(Reference - Report No. WAL 710/633)

Summary of Ballistic Tests Conducted at Watertown Arsenal on Thin-Gauge Samples of a Modified SAE 4340 Steel in Three Conditions of Hardness

C	Mn	P	S	Si	Ni	Cr	Mo	V
.30/.40	.50/.80	.025 max.	.025 max.	.20/.35	1.50/2.00	.70/.90	.25/.50	.15 min.

Sample	Hardness	Gauge	Ballistic Limit (F/S) G-1-A[1]	G-1-S[2]	G-2[3]	Cal. .45[4]
Item 4	28 Rc	.042"	405	--	--	--
Normalized, oil	29 Rc	.040"	-	820	1104	--
quenched & tempered	31 Rc	.041"	-	--	--	592
Item 5	38 Rc	.040"	342	--	--	--
Normalized, oil	39 Rc	.040"	-	817	1043	--
quenched & tempered	40 Rc	.039"	-	--	--	493 PTP
Item 6	47 Rc	.039"	325	--	--	626
Normalized, oil quenched & tempered	52 Rc	.039"	-	810	1129	646
For Comparison: Hadfield Manganese Steel	88 Rb	.040"	-	900	1600	900

1. Caliber .30 fragment-simulating projectile - 150 grains.
2. Caliber .30 fragment-simulating projectile - 34 grains.
3. Caliber .22 fragment-simulating projectile - 17 grains.
4. Caliber .45 steel jacketed ball projectile - 230 grains.

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TABLE VIII

(Reference - Report No. WAL 710/634)

Summary of Ballistic Tests Conducted at Watertown Arsenal on Light-Gauge Samples of Si-Ni-Cr-Mo Steel and Cr-Mo-V Steel

Chemical Composition

	C	Mn	Si	Cr	Ni	Mo	V
843-1, 2, 3	.44	.57	.22	1.08	---	.90	.21
1739-1, 2, 3	.35	.81	.96	.75	.66	.25	--

Heat Treatment	Sample	Gauge	Hardness	Ballistic Limit (F/S) G-21	Ballistic Limit (F/S) Cal. .452
Oil Quench: 1600°F. - 10 min.	843-3	.041"	37 Rc	1132	510
Oil quench 1050°F. - 1 hour Air Cool	1739-3	.041"	23 Rc	1089	532
Austemper: 1500°F. - 10 min.	843-1	.042"	46 Rc	1166	560
Quench in salt at 600°F. Hold 1 hour Water quench	1739-1	.042"	46 Rc	1212	613
Normalize: 1600°F. - 10 min. Air Cool	843-2	.041"	51 Rc	1322	777
	1739-2	.040"	49 Rc	--	783
For Comparison: Hadfield Manganese Steel	--	.040"	88 Rb	1600	900

1. Caliber .22 fragment-simulating projectile - 17 grains.
2. Caliber .45 steel-jacketed ball projectiles - 230 grains.

APPENDIX A

TABLE IX

(Reference - Report No. WAL 710/638)

Summary of Ballistic Tests Conducted at Watertown Arsenal on Samples of an Austenitic Steel Submitted by Jessop Steel Co.

Sample	Gauge	Hardness	Ballistic Limit (F/S) Cal. .45[1]	Ballistic Limit (F/S) G-2[2]
As Annealed	.042"	255 BHN	728	
	.042"	255 BHN		1171
1/4 Hard	.045"	270 BHN	689	
	.045"	270 BHN		1283
1/2 Hard	.042"	282 BHN	625	
	.044"	282 BHN		1155
Full Hard	.045"	301 BHN	685	
	.046"	295 BHN		1237
For Comparison: Hadfield Manganese Steel	.042"	88 Rb	920	1630

1. Cal. .45 (steel-jacketed) ball projectile - 230 grains.
2. Cal. .22 fragment-simulating projectiles - 17 grains.

APPENDIX A

TABLE X

(Reference - Report No. WAL 710/648)

Summary of Ballistic Tests Conducted at Watertown Arsenal on Light-Gauge Mn-Mo Steel As-Quenched and As-Tempered at 300°F., 400°F., and 500°F.

Chemical Composition

C	Mn	Si	S	P	Mo	Hardening Treatment
.27	1.80	.21	.018	.015	.51	1575°F. - Water Quench

Sample	Gauge	Tempering	Hardness (Rc)		Ballistic Limit (F/S)	
			Pre-Temper	Post Temper	G-2[1]	Cal. .45[2]
A-1	.041"	1 hr. - 500°F.	42-47	41-43	1004	less than 421
A-2	.041"	1½ hr. - 400°F.	38-44	40-42	1072	378
A-3	.041"	2 hrs. - 300°F.	50-53	47-50	1327	567
A-4	.039"	none	51-53	51-53	1163	651
B-1	.051"	1 hr. - 500°F.	44-48	39-41	1755	970
B-2	.051"	1½ hr. - 400°F.	49-51	45-46	1715	963
B-3	.051"	2 hrs. - 300°F.	50-52	47-49	1741	962
B-4	.051"	none	50-52	50-52	1750	plate split
For Comparison:						
Hadfield	.040"		88 Rb		1600	900
Manganese Steel	.050"		88 Rb		1750	1000

1. Cal. .22 fragment-simulating projectiles - 17 grains.
2. Cal. .45 (steel-jacketed) ball projectile - 230 grains.

APPENDIX A

TABLE XI

(Reference - Report No. WAL 710/654)

Summary of Ballistic Tests Conducted at Watertown Arsenal on Samples of Mn-Mo Steel Made by Jones and Laughlin Steel Corporation and Heat Treated by Breeze Corporations, Inc.

Chemical Composition

C	Mn	Si	S	P	Mo
.25	1.61	.22	.017	.020	.50

Hardening Treatment

All Plates Quenched in Oil from 1600°F.

Sample	Gauge	Heat Treatment After Quenching	Hardness	Ballistic Limit (F/S) Cal. .45[1]	Ballistic Limit (F/S) G-2[2]
HF-1	.042"	As Quenched	47 Rc	544	1092
HF-2	.041"	2 hrs. - 300°F.	45 Rc	546	1234
HF-3	.042"	1½hrs. - 450°F.	44 Rc	420	1215
HF-4	.040"	1 hr. - 600°F.	40 Rc	<436	1270
HF-5	.040"	Austemper - 300°F.	45 Rc	592	1086
For Comparison:					
Average Hadfield Manganese steel	.040"	-	88 Rb	900	1600

1. Cal. .45 (steel-jacketed) ball projectile - 230 grains.
2. Cal. .22 fragment-simulating projectile - 17 grains.

APPENDIX A

TABLE XII

(Reference - Report No. WAL 710/667)

Summary of Penetration Tests Conducted at Watertown Arsenal on

Samples of Silico-Manganese Spring Steel

Chemical Composition

C	Mn	P	S	Si
.55/.65	.70/1.00	.040 max.	.040 max.	1.80/2.20

All plates normalized, oil quenched and tempered.

Sample	Gauge	Hardness	Ballistic Limit (F/S) G-2[1]	Ballistic Limit (F/S) Cal. .45[2]
7-1	.042"	40 Rc	—	682
7-1	.043"	43 Rc	1170	-
8-1	.039"	51 Rc	—	679
8-5	.042"	49 Rc	1760	-
For Comparison: Hadfield Manganese Steel (Average)	.042"	88 Rb	1630	920

1. Cal. .22 fragment-simulating projectile - 17 grains.
2. Cal. .45 (steel-jacketed) ball projectile - 230 grains.

APPENDIX A

TABLE XIII

(Reference - Report No. WAL 710/668)

Summary of Results of Tests Conducted at Watertown Arsenal on

Samples of Austempered Mn-Mo Steel

Chemical Analysis

C	Mn	Si	S	P	Mo
.25	1.61	.22	.017	.020	.50

Sample	Actual Gauge	Hardness Rockwell "C"	Austempering Temperature (In Salt Bath)	Ballistic Limit (F/S) Cal. .45[1]
HF-6	.040"	46	450°F.	553
HF-7	.042"	44	500°F.	580
HF-8	.043"	42	600°F.	489
HF-9	.042"	38	700°F.	536
HF-10	.043"	45	500°F. (with agitation)	632
For Comparison:				
Average Hadfield Manganese Steel	.043"	—	—	930
Ne-8630 Steel[2]	.042"	49	—	880

1. Cal. .45 steel-jacketed ball projectile - 230 grains.
2. WAL 710/672. NE-8630 steel heat treated at Watertown Arsenal.

APPENDIX A

TABLE XIV

(Reference - Report No. WAL 710/672)

Summary of Results of Tests Conducted at Watertown Arsenal on Samples of X4130 Steel and 8630 Steel

Sample No.	Condition	C	Mn	P	S	Si	Ni	Cr	Mo		Actual Gauge	Hardness Rockwell "C"	Ballistic Limit (F/S) Cal. .45[1]	G-2[2]
C9-1	Heat Treated	.29	.47	.017	.025	.28	-	.98	.20	X4130	.048"	51	917	1683
C9-2	As Rolled	.29	.47	.017	.025	.28	-	.98	.20	X4130	.048"	22	616	—
C10-1	Heat Treated	.29	.73	.018	.028	.25	.46	.52	.17	8630	.042"	49	880	1390
C10-2	As Rolled	.29	.73	.018	.028	.25	.46	.52	.17	8630	.043"	24	378	—
For Comparison:														
Average Hadfield Manganese Steel											.042"	—	920	1530
											.048"	—	980	1720

1. Cal. .45 steel-jacketed ball projectile - 230 grains.

2. Cal. .22 fragment-simulating projectile - 17 grains.

APPENDIX A

TABLE XVa

(Reference - Report No. WAL 710/693)

Summary of Results of Tests on 18-8 Stainless Steel

Sample No.	Actual Gauge	Hardness (Rockwell "C")	% Nickel	Condition	Ballistic Limit (F/S) Cal. .45[1]	0-2[2]
O-1	.042"	27	7.07	1/4 Hard	638	—
O-2	.042"	27	7.07	1/4 Hard	-	1055
O-4	.042"	27	7.07	1/4 Hard	616	—
O-5	.042"	27	7.07	1/4 Hard	-	1175
A-1	.042"	35	7.07	1/2 Hard	624	—
A-2	.042"	35	7.07	1/2 Hard	-	1052
B-1	.042"	42	7.07	Full Hard	656	—
B-2	.042"	42	7.07	Full Hard	-	1095
B-3	.042"	41	7.07	Full Hard	620	—
B-4	.041"	42	7.07	Full Hard	575	—
C-1	.041"	31	8.75	1/4 Hard	495	—
C-2	.042"	31	8.75	1/4 Hard	-	985
D-1	.042"	34	8.75	1/2 Hard	445	—
D-2	.042"	34	8.75	1/2 Hard	-	1033
E-1	.041"	39	8.75	Full Hard	462	—
E-2	.042"	39	8.75	Full Hard	-	900
F-1	.042"	30	9.53	1/4 Hard	433	—
F-2	.042"	29	9.53	1/4 Hard	-	1038
G-1	.041"	34	9.53	1/2 Hard	390	—
G-2	.042"	34	9.53	1/2 Hard	-	975
H-1	.040"	37	9.53	Full Hard	377	—
H-2	.042"	36	9.53	Full Hard	-	915
For Comparison:						
Hadfield Manganese Steel (Average)	.042"	—	—	-	920	1630

1. Cal. .45 Steel-jacketed ball projectile—230 grains.
2. Cal. .22 flak-simulating projectile - 17 grains.

APPENDIX A

TABLE XVb

(Reference - Report No. WAL 710/593)

Chemical Composition and Physical Properties of Samples of 18-8 Stainless Steel as Reported by Republic Steel Corporation

Sample No.	Chemical Composition								Yield Strength	Tensile Strength	Elongation (2")
	C	Mn	P	S	Si	Ni	Cr	Temper			
O-1 to O-5	.12	1.18	.023	.010	.44	7.07	17.90	1/4 Hard	101,620	140,320	29.5
A-1, A-2	.10	1.25	.035	.014	.45	7.07	18.14	1/2 Hard	117,970	164,440	17.5
B-1 to B-4	.10	1.25	.035	.014	.45	7.07	18.14	Full Hard	147,700	195,180	12.0
C-1, C-2	.08	1.12	.021	.015	.54	8.75	17.02	1/4 Hard	115,250	137,880	19.5
D-1, D-2	.08	1.12	.021	.015	.54	8.75	17.02	1/2 Hard	129,280	155,900	12.5
E-1, E-2	.08	1.12	.021	.015	.54	8.75	17.02	Full Hard	156,700	181,200	9.5
F-1, F-2	.11	1.07	.023	.010	.35	9.53	17.96	1/4 Hard	110,200	138,800	16.0
G-1, G-2	.11	1.07	.023	.010	.35	9.53	17.96	1/2 Hard	140,570	166,680	10.0
H-1, H-2	.11	1.07	.023	.010	.35	9.53	17.96	Full Hard	164,750	189,100	7.5

APPENDIX A

TABLE XVI

(Reference - Report No. WAL 710/697)

Summary of Tests Conducted at Watertown Arsenal on Samples of

N.E. 8620 Steel Supplied by Republic Steel Corporation

Chemical Composition

C	Mn	P	S	Si	Ni	Cr	Mo
.18	.89	.019	.020	.30	.55	.50	.15

Sample No.	Actual Gauge	Hardness Rockwell "C"	Tempering Temperature	Ballistic Limit (F/S) Cal. .45[1]	Ballistic Limit (F/S) G-2[2]
A	.045"	31	900°F.	486	--
B	.044"	29	1000°F.	426	--
C	.044"	25	1100°F.	439	--
D	.045"	19	1200°F.	453	--
E	.044"	43	As Quenched	548	--
F	.044"	43	As Quenched	526	--
G	.044"	42	As Quenched	-	1307
H	.044"	39	As Quenched	-	1155
For Comparison:					
Average Hadfield Manganese Steel	.044"	--	-	940	1660

1. Cal. .45 steel-jacketed ball projectile - 230 grains.
2. Cal. .22 flak-simulating projectiles - 17 grains.

APPENDIX A

TABLE XVII

(Reference - Report No. WAL 710/702)

Summary of Ballistic Tests Conducted at Watertown Arsenal on Samples of Ni-Mo and Si-Cr-Mo-Zr Steels Submitted by The American Rolling Mill Company

Sample No.	Heat Treatment	Hardness (Rc)	Actual Gauge	Ballistic Limit (F/S) .45[1]	G-2[2]	G-1-A[3]	G-1-S[4]
11-1	As quenched in oil from 1450°F.	34	.049"	514	—	—	—
11-2	As quenched in oil from 1450°F.	39	.047"	-	1030	378	825
12-1	Oil quenched from 1450°F. Drawn at 300°F.	35	.048"	488	—	—	—
12-2	Oil quenched from 1450°F. Drawn at 300°F.	40	.047"	-	1155	403	753
13-1	Oil quenched from 1450°F. Drawn at 600°F.	35	.050"	438	—	—	—
13-2	Oil quenched from 1450°F. Drawn at 600°F.	37	.047"	-	1045	383	778
14-1	Oil quenched from 1450°F. Drawn at 900°F.	26	.048"	446	—	—	—
14-2	Oil quenched from 1450°F. Drawn at 900°F.	28	.048"	-	950	345	917
15-1	Oil quenched from 1450°F. Drawn at 1200°F.	20	.049"	500	—	—	—
15-2	Oil quenched from 1450°F. Drawn at 1200°F.	20	.049"	-	893	370	740
16-1	Normalized from 1650°F.	18	.048"	568	—	—	—
16-2	Normalized from 1650°F.	17	.048"	-	1085	391	785
17-1	Quenched from 1450°F. into salt bath at 575°F. for 10 minutes.	29	.049"	487	—	—	—
17-2	"	31	.049"	-	935	396	820

Chemical Composition

C	Mn	Si	P	S	Ni	Cr	Mo	Zr	Cu
.10	.54	.24	.012	.021	3.84	—	.34	—	.24

APPENDIX A

TABLE XVII (Cont'd)

Chemical Composition

C	Mn	Si	P	S	Ni	Cr	Mo	Zr	Cu
.25	.88	.81	.019	.021	—	.82	.14	.14	.064

Sample No.	Heat Treatment	Hardness (Rc)	Actual Gauge	Ballistic Limit (F/S) .45[1]	G-2[2]	G-1-A[3]	G-1-S[4]
21-1	As quenched in oil from 1650°F.	45	.049*	689	—	—	—
21-2	As quenched in oil from 1650°F.	44	.047*	-	1660	480	1050
22-1	Oil quenched from 1650°F. Drawn at 300°F.	46	.048*	537	—	—	—
22-2	Oil quenched from 1650°F. Drawn at 300°F.	44	.045*	-	1685	423	975
23-1	Oil quenched from 1650°F. Drawn at 600°F.	43	.049*	579	—	—	—
23-2	Oil quenched from 1650°F. Drawn at 600°F.	41	.047*	-	1305	500	948
24-1	Oil quenched from 1650°F. Drawn at 900°F.	36	.043*	489	—	—	—
24-2	Oil quenched from 1650°F. Drawn at 900°F.	35	.046*	-	1097	470	828
25-1	Oil quenched from 1650°F. Drawn at 1200°F.	20	.049*	539	—	—	—
25-2	Oil quenched from 1650°F. Drawn at 1200°F.	23	.047*	-	1055	378	830
26-1	Normalized from 1650°F.	29	.050*	684	—	—	—
26-2	Normalized from 1650°F.	28	.048*	-	1370	430	940
27-1	Quenched from 1600°F. into salt bath at 675°F. for 10 minutes.	38	.050*	684	—	—	—
27-2	"	43	.052*	-	1195	426	940
27-3	"	33	.050*	615	—	—	—
For Comparison: Hadfield Manganese Steel		—	.045*	950	1675	500	1050

*The ladle carbon of this heat was 0.20 but apparently decarburization occurred during re-rolling.

1. Cal. .45 steel-jacketed ball projectiles - 230 grains.
2. Cal. .22 fragment-simulating projectile - 17 grains.
3. Cal. .30 fragment-simulating projectile - 150 grains.
4. Cal. .30 fragment-simulating projectile - 34 grains.

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TABLE XVIII

(Reference - Report No. WAL 710/712)

Summary of Ballistic Tests Conducted at Watertown Arsenal on

Samples of Hadfield Manganese Steel Submitted by Carnegie-Illinois Steel Corporation

Sample No.	Actual Gauge	Hardness	Ballistic Limits (F/S) G-1-S[1]	G-1-A[2]	G-2[3]	.45[4]	.30 Ball[5]	.30 Carb.[6]
12-1	.032"	83 Rb	815	--	1215	--	--	--
12-2	.032"	85 Rb	--	--	--	704	--	--
12A-1	.041"	85 Rb	995	--	1600	--	--	--
12A-2	.041"	83 Rb	--	--	--	946	--	--
12A-3	.041"	82 Rb	--	--	--	--	1040	1248
12B-1	.053"	90 Rb	--	--	--	1096	--	--
12B-2	.053"	91 Rb	--	--	--	--	1229	1375
12B-3	.052"	91 Rb	--	--	--	--	1261	1410
12B-4	.052"	90 Rb	--	--	--	1100	--	--
12B-5	.053"	91 Rb	1425	--	--	--	--	--
12B-6	.052"	90 Rb	--	560	1780	--	--	--
12C-1	.063"	89 Rb	--	--	--	1266	1270	1448
12C-2	.063"	87 Rb	--	--	--	--	1265	1476
12D-1	.069"	90 Rb	--	--	--	--	1344	1618
12D-2	.069"	90 Rb	--	--	--	--	--	1433
12E-1	.079"	89 Rb	--	--	--	--	1498	1544
12E-2	.080"	89 Rb	--	--	--	--	--	1503

1. Cal. .30 fragment-simulating projectile - 34 grains.
2. Cal. .30 fragment-simulating projectile - 150 grains.
3. Cal. .22 fragment-simulating projectile - 17 grains.
4. Cal. .45 steel-jacketed ball projectile - 230 grains.
5. Cal. .30 ball M2 projectile.
6. Cal. .30 carbine ball projectile.

APPENDIX A

TABLE XIX

(Reference - Report No. WAL 710/738)

Resistance of Hadfield Manganese Steel in Form of a Helmet, M1, to Perforation by the Fragment-Simulator, G-2

Thickness of Helmet at Point of Impact	Apparent Ballistic Limit (A)
.036"	965 f/s
.037"	985
.038"	1000
.039"	1015
.040"	1040
.041"	1070
.042"	1110
.043"	1155
.044"	1210
.045"	1275

APPENDIX A

TABLE XX

Comparative Resistance of Various Samples of Steels to Perforation

by Cal. .45 Ball Projectiles

Description of Material	Actual Thick-ness	Ballistic Limit	Figure of Merit*	Reference
C10-2 8630 steel as rolled	.043"	378	.41	Table XIV
A-2 Mn-Mo Steel	.041"	378	.42	Table X
H-1 18-8 Stainless	.040"	377	.42	Table XVa
G-1 18-8 Stainless	.041"	390	.43	Table XVa
13-1 Ni-Mo Steel	.050"	438	.44	Table XVII
B NE86 Steel	.044"	426	.45	Table XVI
14-1 Ni-Mo Steel	.048"	446	.46	Table XVIII
HF-3 Mn-Mo Steel	.042"	420	.46	Table XI
A-1 Mn-Mo Steel	.041"	421	.46	Table X
F-1 18-8 Stainless	.042"	433	.47	Table XVa
C NE 8620	.044"	439	.47	Table XVI
HF-4 Mn-Mo	.040"	436	.48	Table XI
D-1 18-8 Stainless	.042"	445	.48	Table XVa
D NE 8620 Steel	.045"	453	.48	Table XVI
17-1 Ni-Mo Steel	.049"	487	.49	Table XVII
24-1 Si-Cr-Mo-Zr Steel	.049"	487	.49	Table XVII
12-1 Ni-Mo Steel	.048"	488	.50	Table XVII
15-1 Ni-Mo Steel	.049"	500	.50	Table XVII
A NE 8620 Steel	.045"	486	.51	Table XVI
E-1 18-8 Stainless Steel	.041"	462	.51	Table XVb
11-1 Ni-Mo Steel	.049"	514	.52	Table XVII
HF-8 Mn-Mo Steel	.043"	489	.53	Table XIII
C-1 18-8 Stainless	.041"	495	.54	Table XVa
25-1 Si-Cr-Mo-Zr Steel	.049"	539	.54	Table XVII
22-1 Si-Cr-Mo-Zr Steel	.048"	537	.55	Table XVII
GT-10 Mn-Mo Steel	.040"	494	.55	Table III
843-3 Cr-Mo-V Steel	.041"	510	.56	Table VIII
F NE 8620 Steel	.044"	526	.56	Table XVI
16-1 Ni-Mo Steel	.048"	568	.58	Table XVII
HF-9 Mn-Mo Steel	.042"	536	.58	Table XIII

TABLE XX (Cont'd)

Description of Material	Actual Thick-ness	Ballistic Limit	Figure of Merit*	Reference
9 .70" carbon Amola steel	.039"	514	.58	Table IV
23-1 Si-Cr-Mo-Zr Steel	.049"	579	.58	Table XVII
HF-1 Mn-Mo Steel	.042"	544	.58	Table XI
1739-3 Si-Ni-Cr-Mo Steel	.041"	532	.58	Table VIII
E NE 8620 Steel	.044"	548	.59	Table XVI
HF-2 Mn-Mo Steel	.041"	546	.60	Table XI
HF-6 Mn-Mo Steel	.040"	553	.61	Table XIII
843-1 Cr-Mo-V Steel	.042"	560	.61	Table VIII
HF-7 Mn-Mo Steel	.042"	580	.62	Table XIII
27-3 Si-Cr-Mo-Zr Steel	.050"	615	.62	Table XVII
A-3 Mn-Mo Steel	.041"	567	.62	Table X
B-4 18-8 Stainless	.041"	575	.63	Table XVA
31 Rc Modified SAE 4340	.041"	592	.65	Table VII
1/2" Hard Stainless (Rockwell C-33)	.048"	646	.66	Table II
HF Mn-Mo Steel	.040"	592	.66	Table XI
09-2 X-4130 As-Rolled	.048"	616	.67	Table XIV
0-4 18-8 Stainless Steel	.042"	616	.67	Table XVa
B-3 18-8 Stainless Steel	.042"	620	.67	Table XVa
SAE 4330 (Rockwell C-34)	.050"	665	.67	Table II
1739-1 (Si-Cr-Ni-Mo Steel)	.042"	613	.67	Table VIII
27-1 (Si-Cr-Mo-Zr Steel)	.050"	684	.68	Table XVII
26-1 Si-Cr-Mo-Zr Steel	.050"	684	.68	Table XVII
A-1 18-8 Stainless Steel	.042"	624	.68	Table XVa
Half-hard Hadfield Manganese	.040"	613	.68	Table VI
HF-10 Mn-Mo Steel	.043"	632	.68	Table XIII
1/2 Hard Austenitic Steel	.042"	625	.68	Table IX
0-1 18-8 Stainless Steel	.042"	638	.69	Table XVa
3/4 Hard (Hadfield Manganese)	.040"	625	.69	Table VI
Item 10 (.70% Carbon Amola Steel)	.039"	615	.69	Table IV
Full Hard Stainless (Rockwell C-45)	.044"	658	.70	Table II
47 Rc (Modified SAE 4340 Steel)	.039"	626	.70	Table VII
21-1 Si-Cr-Mo-Zr Steel	.049"	689	.70	Table XVII
B-1 18-8 Stainless Steel	.042"	656	.71	Table XVa

APPENDIX A

TABLE XX (Cont'd)

Description of Material	Actual Thick-ness	Ballistic Limit	Figure of Merit*	Reference
SAE 4330 Rockwell C-36	.048"	698	.71	Table II
A-4 Mn-Mo Steel	.039"	651	.72	Table X
Full Hard (Austenitic Steel)	.045"	685	.72	Table IX
52 Rc (Modified SAE Steel)	.039"	646	.73	Table VII
1/4" Hard (Austenitic Steel)	.045"	689	.73	Table IX
7-1 Siloco-Manganese	.042"	682	.74	Table XII
8-1 Siloco-Manganese	.039"	679	.76	Table XII
C (Ferritic Steel)	.048"	745	.76	Table I
Austenitic Steel	.042"	728	.79	Table IX
GT-9 Mn-Mo	.039"	699	.79	Table III
I (Ferritic Steel)	.048"	822	.84	Table I
843-2 Cr-Mo-V Steel	.041"	777	.85	Table VIII
1739-2 Si-Ni-Cr-Mo Steel	.040"	783	.87	Table VIII
11-A .70% Carbon Amola Steel	.044"	830	.88	Table IV
GT-2 Mn-Mo Type	.048"	874	.89	Table III
1/4 Rockwell Stainless (Rockwell C-27)	.051"	912	.90	Table II
E (Hadfield Steel)	.043"	848	.91	Table I
11-B (70% Carbon Amola Steel)	.041"	827	.91	Table IV
A Hadfield Steel	.046"	898	.94	Table I
B-3 Mn-Mo Steel	.051"	962	.95	Table X
B-2 Mn-Mo Steel	.051"	963	.95	Table X
B (Ferritic Steel)	.048"	940	.96	Table I
C-10-1 8630 Steel (Heat Treated)	.042"	880	.96	Table XIV
NE 8630 Hadfield Manganese	.042"	880	.96	Table XIII
B-1 (Light Weight Mn-Mo Steel)	.051"	970	.96	Table X
Hadfield Manganese (Average)	.050"	1000	1.00	Table II
C-9-1 X 4130 Heat Treated	.048"	917	1.00	Table XIV
Hadfield Manganese, As Annealed	.044"	949	1.01	Table VI
12A-2 Hadfield Manganese	.041"	946	1.04	Table XVIII
GT-3 Mn-Mo Steel	.050"	1042	1.04	Table III
GT-1 Mn-Mo Type Steel	.049"	1027	1.04	Table III
A-62 Hadfield Steel	.044"	1131	1.20	Table I
F Hadfield Steel	.043"	1117	1.20	Table I

APPENDIX A

TABLE XX (Cont'd)

*Figure of merit determined from the formula:

$\frac{V_{SUB} \times 100}{V_{HAD}}$ where V_{SUB} is the ballistic limit of the subject sample and V_{HAD} is the ballistic limit characteristic of samples of Hadfield manganese steel of equivalent weight.

APPENDIX A

TABLE XXI

Comparative Resistance of Various Samples of Steels to Perforation

by Cal. .22 Fragment-Simulating Projectile, G-2

Description of Material	Actual Thick-ness	Ballistic Limit	Figure of Merit*	Reference
15-2 Ni-Mo Steel	.049"	893	.51	Table XVII
17-2 Ni-Mo Steel	.049"	935	.54	Table XVII
14-2 Ni-Mo Steel	.048"	950	.55	Table XVII
E-2 18-8 Stainless Steel	.042"	900	.55	Table XVa
H-2 18-8 Stainless Steel	.042"	915	.56	Table XVa
C-2 18-8 Stainless Steel	.042"	985	.60	Table XVa
11-2 Ni-Mo Steel	.047"	1030	.60	Table XVII
G-2 18-18 Stainless Steel	.042"	975	.60	Table XVa
13-2 Ni-Mo Steel	.047"	1045	.61	Table XVII
A-1 Mn-Mo Steel	.041"	1004	.62	Table X
25-2 Si-Cr-Mo-Zr Steel	.047"	1055	.62	Table XVII
11-B (.70 Carbon Amola Steel)	.041"	1020	.63	Table IV
D-2 18-8 Stainless Steel	.042"	1033	.63	Table XVa
16-2 Ni-Mo Steel	.048"	1085	.63	Table XVII
F-2 18-8 Stainless Steel	.042"	1038	.64	Table XVa
24-2 Si-Cr-Mo-Zr Steel	.046"	1097	.65	Table XVII
A-2 18-8 Stainless Steel	.042"	1052	.65	Table XVa
O-2 18-8 Stainless Steel	.042"	1055	.65	Table XVa
39 Rc Modified SAE Steel	.040"	1043	.65	Table VII
A-2 Mn-Mo Steel	.041"	1072	.66	Table X
9 (.70% Carbon Amola Steel)	.039"	1053	.66	Table IV
10 (.70% Carbon Amola Steel)	.040"	1051	.66	Table IV
1739-3 (Si-Ni-Cr-Mo Steel)	.041"	1089	.67	Table VIII
B-2 18-8 Stainless Steel	.042"	1095	.67	Table XVa
HF-1 Mn-Mo Steel	.042"	1092	.67	Table XI
Full Hard Stainless (Rockwell C-45)	.044"	1115	.67	Table II
12-2 Ni-Mo Steel	.047"	1155	.68	Table XVII
1/2" Hard Stainless (Rockwell C-33)	.048"	1173	.68	Table II
HF-5 Mn-Mo Steel	.040"	1086	.68	Table XI
29 Rc (Modified SAE 4340 Steel)	.040"	1104	.69	Table VII

APPENDIX A

TABLE XXI (Cont'd)

Description of Material	Actual Thick-ness	Ballistic Limit	Figure of Merit*	Reference
11-9 (.70% Carbon Amola Steel)	.046"	1165	.69	Table III
GT-10 Mn-Mo Type Steel	.040"	1105	.69	Table III
1/2 Hard (Austenitic Steel)	.044"	1155	.70	Table IX
843-3 (Cr-Mo-V Steel)	.041"	1132	.70	Table VIII
H NE 8620 Steel	.044"	1155	.70	Table XVI
52 Rc (Modified SAE 4340 Steel)	.039"	1129	.71	Table VII
6-1 Silico Manganese	.043"	1170	.71	Table XII
0-5 18-8 Stainless Steel	.042"	1175	.72	Table XVa
Austenitic Steel	.042"	1171	.72	Table IX
843-1 Cr-Mo-V Steel	.042"	1166	.72	Table VIII
Full Hard (Austenitic Steel)	.046"	1237	.73	Table IX
A-4 Mn-Mo Steel	.039"	1163	.73	Table X
1739-1 Si-Ni-Cr-Mo Steel	.042"	1212	.74	Table VIII
3/4 Hard (Hadfield Manganese Steel)	.040"	1184	.74	Table VI
HF-3 Mn-Mo Steel	.042"	1215	.75	Table XI
HF-2 Mn-Mo Steel	.041"	1234	.76	Table XI
1/4 Hard (Austenitic Steel)	.045"	1283	.77	Table IX
Half Hard (Hadfield Manganese)	.040"	1232	.77	Table VI
23-2 Si-Cr-Mo-Zr Steel	.047"	1305	.77	Table XVII
G NE 8620 Steel	.044"	1307	.79	Table XVI
HF-4 Mn-Mo Steel	.040"	1270	.79	Table XI
26-6 Si-Cr-Mo-Zr Steel	.048"	1370	.80	Table XVII
843-2 Cr-Mo-V Steel	.041"	1322	.82	Table VIII
C10-1 8630 Steel - Heat Treated	.042"	1390	.85	Table XIV
GT-9 Mn-Mo Type Steel	.039"	1375	.87	Table III
A-3 Mn-Mo Type Steel	.041"	1327	.88	Table X
SAE 4330 (Rockwell C-34)	.050"	1545	.88	Table II
.050" Steel Sheets & Multi-Layered Assemblies	.050"	1574	.90	Table V
SAE 4330 (Rockwell C-36)	.043"	1553	.90	Table II

TABLE XXI (Cont'd)

Description of Material	Actual Thick-ness	Ballistic Limit	Figure of Merit*	Reference
Hadfield Manganese, As Annealed	.040"	1510	.94	Table VI
Hadfield Manganese, As Annealed	.044"	1570	.94	Table VI
1/4" Hard Stainless (Rockwell C-27)	.051"	1675	.95	Table II
B-2 Mn-Mo Steel	.051"	1715	.97	Table X
C9-1 X4130 Heat Treated	.048"	1683	.98	Table XIV
12A-1 Hadfield Manganese	.041"	1600	.99	Table XVIII
B-4 Mn-Mo Steel	.051"	1750	.99	Table X
B-3 Mn-Mo Steel	.051"	1741	.99	Table X
B-1 Mn-Mo Steel	.051"	1755	.99	Table X
Hadfield Manganese (Average)	.050"	1750	1.00	Table II
21-2 Si-Cr-Mo-Zr Steel	.047"	1660	1.00	Table XVII
22-2 Si-Cr-Mo-Zr	.045"	1685	1.01	Table XVII
GT-2 Mn-Mo Type Steel	.048"	1775	1.03	Table III
8-5 Silico Manganese	.042"	1760	1.08	Table XII
GT-3 Mn-Mo Type Steel	.050"	1920	1.10	Table III
GT-1 Mn-Mo Type Steel	.049"	1913	1.10	Table III

*Figure of merit determined from the formula:

$\frac{V_{SUB} \times 100}{V_{HAD}}$ where V_{SUB} is the ballistic limit of the subject sample and V_{HAD} is the ballistic limit characteristic of samples of Hadfield manganese steel of equivalent weight.

APPENDIX B

NON-FERROUS METALS

References
(Applicable to APPENDIX B)

1. O.O. 422.3/11 - Wtn. 470.5/7843, 28 September 1943.
2. O.O. 400.112/8724 - Wtn. 400.112/3147, 10 July 1944.
3. O.O. 470.1/476 - Wtn. 400.1/7854, 13 July 1944.
4. O.O. 426/2179 - Wtn. 400.112/3174, 24 August 1944.
5. O.O. 400.112/10724 - Wtn. 400.112/[illegible], 29 August 1944.
6. O.O. 470.1/41526 - Wtn. 470.1/55, 16 September 1944.
7. O.O. 400.112/11951 - Wtn. 400.112/3227, 7 November 1944.
8. O.O. 471.9/1932 - Wtn. 470.5/101, 14 November 1944.
9. O.O. 471.9/1971 - Wtn. 400.112/3704, 27 November 1944.
10. O.O. 470.1/500 - Wtn. 470.1/127, 29 January 1944.
11. Report No. WAL 710/[illegible], "Resistance of Various Samples of Aluminum Alloys Furnished by Reynolds Metals Co. to Perforation by Fragment-Simulating Projectiles", J. F. Sullivan, 4 January 1945.
12. Report No. WAL 710/307, "Resistance of an Aluminum Alloy (R301-T) to Perforation by Fragment-Simulating Projectiles", J. F. Sullivan, 13 December 1944.
13. Report No. WAL 710/516, "Resistance of Various Numbers of Plies of .0208 Aluminum Alloy Sheets to Perforation by Fragment-Simulating Projectiles", J. F. Sullivan, 29 August 1944.
14. Report No. WAL 710/636, "Resistance of Four Types of Thin Aluminum Alloy Sheet to Perforation by Fragment-Simulating Projectiles", J. F. Sullivan, 23 May 1944.
15. Report No. WAL 710/637, "Resistance of Light-Gauge Aluminum Alloy (75S-T) to Perforation by Fragment-Simulating Projectiles", J. F. Sullivan, 3 July 1944.
16. Report No. WAL 710/708, "Resistance of Several Samples of Aluminum Alloy (24S-T) to Perforation by Fragment-Simulating Projectiles", J. F. Sullivan, 27 November 1944.
17. Report No. WAL [illegible]/715, "Comparison of 24S-T and 75S-T Aluminum Alloys on the Basis of Resistance to Perforation by Fragment-Simulating Projectiles", J. F. Sullivan and E. A. [illegible], 8 January 1945.

References (Continued)

18. Report No. WAL 710/718, "Resistance of Various Numbers of Plies of .020" and .025" Sheets of Aluminum Alloy (AN-A-13 24S-T) to Perforation by Various Fragment-Simulating Projectiles". N. A. Brough, 15 January 1945.

19. Report No. WAL 762/247, "Development of Projectiles to Be Used in Testing Body Armor, to Simulate Flak and 20 mm. H.E. Fragments". J. F. Sullivan, 17 December 1943.

20. Report No. WAL 762/253, "Development of a Projectile, to Be Used in Testing Body Armor, to Simulate Fragments of a 20 mm. H.E. Projectile". J. F. Sullivan, 7 January 1944.

21. Report No. WAL 762/314, "Comparison of 0-2 Projectiles of Various Manufacture". J. F. Sullivan, 23 May 1945.

22. Report No. WAL 710/738, "Resistance of Hadfield Manganese Steel in Form of Helmet, M1, to Perforation by Fragment-Simulator, 0-2". J. F. Sullivan, 26 April 1945.

APPENDIX B

TABLE I

(Reference - Report No. WAL 710/249)

Summary of Ballistic Tests Conducted at Watertown Arsenal on

Several Samples of Aluminum Alloys (R301-W, R301-T)

Submitted by Reynolds Metals Company

Type	Identi-fication	Nominal Gauge	Actual Gauge	Grams/Sq.Ft.	Equiv. Steel Gauge	Ballistic Limit F/S Cal. .45[1]	Ballistic Limit F/S $\emptyset$-2[2]	Ballistic Limit F/S Cal. .30 Carbine[3]
R301-W	A	.125*	.126*	832	.045*	790	-	-
	B	.125	[illegible]	812	.044	691	-	-
	C	.125	[illegible]	818	.044	-	812	-
	D	.125	.124	818	.044	-	810	-
R301-W	A	.156	.152	1003	.054	875	-	-
	B	.156	.154	1016	.055	906	-	-
	E	.156	.155	1023	.055	-	923	-
	F	.156	.154	1016	.055	-	922	-
R301-W	A	.188	.188	1241	.067	1110	-	-
	B	.188	.185	1221	.066	1098	-	-
	D	.188	.186	1228	.066	-	1082	-
	E	.188	.184	1214	.065	-	1127	-
R301-W 14x14	A	.250	.246	1624	.087	-	-	1443
	B	.250	.251	1657	[illegible]	-	1740	-
R301-W	F	.250	.252	1663	.090	-	-	1498
R301-T	A	.156	.155	1023	.055	[illegible]	-	-
	B	.156	.154	1016	.055	[illegible]	-	-
	F	.156	.156	1030	.056	-	945	-
	E	.156	.154	1016	.055	-	937	-
R301-T	A	.250	.249	1643	.089	-	-	1405
	B	.250	.250	1650	.089	-	-	1415
For Comparison:								
Hadfield Manganese Steel		-	-		.045	950	1675	1275

1. Cal. .45 steel-jacketed ball projectile.

2. Cal. .22 fragment-simulating projectile.

3. Cal. .30 carbine ball projectile.

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TABLE II

(Reference - Report No. WAL 710/307)

Summary of Ballistic Tests Conducted at Watertown Arsenal on Samples of R301-T Aluminum Alloy from Reynolds Metals Company

Material	Actual Thickness	Grams/ Sq.Ft.	Equiv. Steel Thick.	Ballistic Limit F/S Cal. .45[1]	0-1-A[2]	0-1-B[3]	0-2[4]
R301-T	.125*	625	.045*	766	-	-	-
R301-T	.129	651	.046	-	440	515	798
R301-T	.154	1016	.055	882	-	-	-
R301-T	.152	1002	.054	-	473	960	873
R301-T	.188	1240	.067	1057	-	-	-
R301-T	.189	1247	.067	-	617	1135	1108
For Comparison:							
Hadfield Manganese Steel	.045	—	-	950	-	-	1675

1. Cal. .45 steel-jacketed ball projectile - 230 grains.

2. Cal. .30 fragment-simulating projectile - 150 grains.

3. Cal. .30 fragment-simulating projectile - 34 grains.

4. Cal. .22 fragment-simulating projectile - 17 grains.

APPENDIX B

TABLE III

(Reference - Report No. WAL 710/516)

Summary of Ballistic Tests Conducted at Watertown Arsenal on Various Numbers of Plies of .020" Aluminum Alloy Sheet

No. Plies	Equivalent Steel Gauge	Ballistic Limit F/S Cal. .45[1]	Ballistic Limit F/S C-2[2]
4	.029"	396	692
5	.036	569	-
6	.043	703	927
7	.050	796	-
8	.057	908	1175
9	.064	1044	-
10	.071	-	1313
12	.086	-	1590
For Comparison:			
Aluminum Alloy (Ave.)	.044	748	827
Hadfield Manganese Steel (Ave.)	.044	946	1660

1. Cal. .45 steel-jacketed ball projectile - 230 grains.

2. Cal. .22 fragment-simulating projectile - 17 grains.

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TABLE IV

(Reference - Report No. WAL 710/636)

Summary of Ballistic Tests Conducted at Watertown Arsenal on

Four Types of Thin Aluminum Alloy Sheets

Sample	Equivalent Steel Gauge	Ballistic Limit F/S	
		C-2[1]	Cal. .45[2]
R301-T	.044"	764	725
R301-W	.045"	842	715
14S-W	.044"	842	729
24S-RT	.044"	874	780
For Comparison:			
Hadfield Manganese	.044"	1660	940

1. Cal. .22 fragment-simulating projectile - 17 grains.

2. Cal. .45 (steel-jacketed) ball projectile - 230 grains.

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TABLE V

(Reference - Report No. WAL 710/657)

Summary of Penetration Tests Conducted at Watertown Arsenal on

Light-Gauge Samples of Aluminum Alloy (75S-T)

Sample	Gauge	Equivalent Steel Gauge	Ballistic Limit F/S	
			G-2[1]	Cal. .45[2]
Lot 38031-1	.127"	.045"	820	818
38031-2	.126	.045	-	776
Lot 38032-1	.123	.044	786	765
38032-2	.124	.044	-	780
Lot 38033-1	.122	.043	825	684
38033-2	.123	.044	-	681
Lot 38034-1	.121	.043	837	839
38034-2	.123	.044	-	788
For Comparison:				
Hadfield Manganese Steel	-	.043	1045	930

1. Cal. .22 fragment-simulating projectile - 17 grains.

2. Cal. .45 (steel-jacketed) ball projectile - 230 grains.

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TABLE VI

(Reference - Report No. WAL 710/708)

Summary of Tests Conducted at Watertown Arsenal on Samples of

24ST Aluminum Furnished by Aberdeen Proving Ground

Sample No.	Actual Gauge	Grams/ Sq.Ft.	Equiv. Steel Gauge	Ballistic Limit F/S .45[1]	G-2[2]	G-1-A[3]	G-1-S[4]
1A	.155*	1015	.055*	-	998	512	1078
1B	.157	1032	.056	-	1050	537	1128
1C	.154	1017	.055	891	-	-	-
1D	.155	1016	.055	900	-	-	-
2A	.158	1040	.056	-	1035	505	1080
2B	.156	1035	.056	-	1015	520	1075
2C	.153	995	.054	843	-	-	-
2D	.156	1031	.056	862	-	-	-
3A	.158	1037	.056	-	1010	538	1072
3B	.155	1020	.055	-	1053	530	1076
3C	.156	1034	.056	896	-	-	-
3D	.15[illegible]	1015	.055	882	-	-	-
4A	.156	1033	.056	-	1015	468	1075
4B	.155	1023	.055	-	968	480	1035
4C	.153	1001	.054	907	-	-	-
4D	.155	1015	.055	902	-	-	-
5A	.158	1035	.056	-	1023	530	1077
5B	.157	1037	.056	-	1035	535	1035
5C	.155	1017	.055	939	-	-	-
5D	.156	1031	.056	937	-	-	-
For Comparison:							
Hadfield Manganese Steel	.045	-	-	950	1675	-	-

1. Cal. .45 steel-jacketed projectile - 230 grains.
2. Cal. .22 fragment-simulating projectile - 17 grains.
3. Cal. .30 fragment-simulating projectile - 150 grains.
4. Cal. .30 fragment-simulating projectile - 34 grains.

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TABLE VII

(Reference - Report No. WAL 710/713)

Summary of Ballistic Tests Conducted at Watertown Arsenal on Samples of 24ST and 75S-T Duralumin Which Had Been Previously Subjected to Fragmentation Tests at Aberdeen Proving Ground

Type	Sample No.	Nominal Gauge	Actual Gauge	Grams/ Sq.Ft.	Equiv. Steel Gauge	Ballistic Limit F/S .45[1]	G-2[2]	G-1-S[3]
75S-T	8	.156"	.154"	1016	.055"	922		
"	8	.156	.154	1008	.054	-	960±25	1063±23
"	9	.156	.160	1043	.056	847		
"	9	.156	.157	1028	.056	-	970± 5	1077±27
"	2	.156	.156	1022	.055	887		
"	2	.156	.155	1016	.055	-	955±10	1083±23
"	11	.125	.127	832	.046	772		
"	11	.125	.123	798	.043	-	775±15	825±10
"	7	.125	.125	821	.044	753		
"	7	.125	.125	816	.044	-	800±25	803±23
"	8	.125	.124	821	.044	790		
"	8	.125	.127	838	.045	-	827±17	898±13
"	1	.102	.100	656	.035	522		
"	1	.102	.101	664	.036	-	728±13	803±23
"	4	.102	.103	672	.036	537		
"	4	.102	.102	674	.036	-	760±30	720±25
"	20	.102	.101	665	.036	541		
"	20	.102	.101	662	.036	-	725±40	723±13
24ST	16-A-53	.156	.156	1031	.056	927		
"	16-A-53	.156	.157	1028	.056	-	1030±10	1025±15
"	7-A-69	.156	.161	1046	.057	880		
"	7-A-69	.156	.157	1022	.055	-	965	1042±17
"	13-A-67	.156	.157	1028	.056	929		
"	13-A-67	.156	.158	1032	.056	-	983±23	1090±15
"	10-B-179	.125	.124	826	.045	720		
"	10-B-179	.125	.128	834	.045	-	823±27	870±25
"	13-A-136	.125	.124	837	.045	777		
"	13-A-136	.125	.128	836	.045	-	825±10	868±17
"	13-13-183	.125	.127	837	.045	736		
"	13-13-183	.125	.126	836	.045	-	835±20	842±27
"	16	.102	.104	684	.037	568		
"	16	.102	.105	678	.037	-	735±20	710±20
"	26	.102	.104	685	.037	539		
"	26	.102	.104	672	.036	-	740±25	690±15
"	29	.102	.104	688	.037	522		
"	29	.102	.104	682	.035	-	775±25	745±10
For Comparison:								
Hadfield Manganese Steel					.045	950	1675	1050

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TABLE VIII

(Reference - Report No. WAL 710/718)

Summary of Ballistic Tests Conducted at Watertown Arsenal on

Samples of AN-A-13 Aluminum Sheets at Various Plies

Type	Sample No.	Ply	Nominal Gauge 1 Ply	Grams/ Sq.Ft.	Equiv. Steel Gauge	Ballistic Limit F/S G-2[1]	G-1-82[2]
AN-A-13	A-6	6	.020*	755	.040*	820±15	700±15
AN-A-13	A-8	8	.020	1007.2	.054	1030±30	782± 7
AN-A-13	A-10	10	.020	1273.7	.069	1253±12	923± 3
AN-A-13	B-4	4	.025	660	.036	763± 3	568±18
AN-A-13	B-5	5	.025	823	.044	850±15	670±20
AN-A-13	B-6	6	.025	968.7	.052	928±13	725±15
AN-A-13	B-7	7	.025	1153	.062	1145±20	815±10
For Comparison:							
Aluminum[3] Alloy (Ave.)		6	.020	-	.043	927	-
Aluminum[4] 24ST (Ave.)	Single Plate		.125	835	.045	827	866

1. Cal. .22 fragment-simulating projectile - 17 grains.

2. Cal. .30 fragment-simulating projectile - 34 grains.

3. WAL 710/586.

4. WAL 710/713.

APPENDIX B

TABLE IX

Comparative Resistance of Various Samples of Aluminum Alloys to

Perforation by Cal. .45 (Steel-Jacketed) Ball Projectiles

Type Alloy	Identification	Actual Gauge	Equiv. Steel Gauge	Ballistic Limit	Figure of Merit*	Reference
75S-T	38034-1	.121"	.043"	839	.90	WAL 710/657 - Table V
75S-T	38031-1	.127"	.045"	818	.85	WAL 710/657 - Table V
75S-T	38034-2	.123"	.044"	788	.84	WAL 710/657 - Table V
75S-T	8	.124"	.044"	790	.84	WAL 710/713 - Table VII
75S-T	38032-2	.124"	.044"	730	.83	WAL 710/657 - Table V
24S-RT	-	-	.044"	780	.83	WAL 710/636 - Table IV
24S-T	13-A-136	.124"	.045"	777	.82	WAL 710/713 - Table VII
75S-T	38031-2	.126"	.045"	776	.82	WAL 710/657 - Table V
R301-T	-	.125"	.045"	766	.81	WAL 710/307 - Table II
75S-T	38032-1	.123"	.044"	765	.81	WAL 710/657 - Table V
75S-T	11	.125"	.046"	772	.80	WAL 710/713 - Table VII
75S-T	7	.125"	.044"	753	.80	WAL 710/713 - Table VII
Alclad 24S-T	7 plies .020"	-	.050"	796	.80	WAL 710/516 - Table III
14S-W	-	-	.044"	729	.78	WAL 710/636 - Table IV
R301-T	-	-	.044"	725	.77	WAL 710/636 - Table IV
24S-T	13-13-163	.125"	.045"	736	.77	WAL 710/713 - Table VII
R301-W	A	.126"	.045"	730	.77	WAL 710/249 - Table I
24S-T	10-B-179	.124"	.045"	720	.76	WAL 710/713 - Table VII
Alclad 24S-T	6 plies .020"	-	.043"	703	.76	WAL 710/516 - Table III
R301-W	-	-	.045"	715	.75	WAL 710/636 - Table IV
R301-W	B	.123"	.044"	691	.74	WAL 710/249 - Table I
75S-T	38033-1	.122"	.043"	684	.74	WAL 710/657 - Table V
75S-T	38033-2	.123"	.044"	681	.72	WAL 710/657 - Table V

*The figure of merit is determined from the formula $\frac{V_{SUB}}{V_{HAD}}$ where

V_{SUB} is the ballistic limit of the sample tested and V_{HAD} is the characteristic ballistic limit of an equivalent weight of Hadfield manganese steel.

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TABLE X

Comparative Resistance of Various Samples of Aluminum Alloys to

Perforation by Cal. .22 Fragment-Simulating Projectile, G-2

Type Alloy	Identification	Actual Gauge	Equiv. Steel Gauge	Ballistic Limit	Figure of Merit*	Reference
Alclad 24S-T	6 plies .020"	-	.043"	927	.56	WAL 710/516 - Table III
24S-RT	-	-	.044"	874	.53	WAL 710/636 - Table IV
Alclad 24S-T	6 plies .020"	-	.040"	820	.51	WAL 710/718 - Table VIII
Alclad 24S-T	5 plies .025"	-	.044"	850	.51	WAL 710/718 - Table VIII
75S-T	38034-1	.121"	.043"	837	.51	WAL 710/657 - Table V
14S-W	-	-	.044"	842	.51	WAL 710/636 - Table IV
R301-W	-	-	.045"	842	.50	WAL 710/636 - Table IV
24S-T	13-13-183	.127"	.045"	835	.50	WAL 710/713 - Table VII
75S-T	38033-1	.122"	.043"	825	.50	WAL 710/657 - Table V
R301-W	C	.125"	.044"	812	.49	WAL 710/249 - Table I
R301-W	D	.125"	.044"	810	.49	WAL 710/249 - Table I
75S-T	38031-1	.127"	.045"	820	.49	WAL 710/657 - Table V
75S-T	8	.127"	.045"	827	.49	WAL 710/713 - Table VII
24S-T	10-B-179	.128"	.045"	823	.49	WAL 710/713 - Table VII
24S-T	13-A-136	.128"	.045"	825	.49	WAL 710/713 - Table VII
75S-T	7	.125"	.044"	800	.48	WAL 710/713 - Table VII
75S-T	11	.123"	.043"	775	.47	WAL 710/713 - Table VII
75S-T	38032-1	.123"	.044"	786	.47	WAL 710/657 - Table V
R301-T	-	.129"	.046"	798	.47	WAL 710/307 - Table II
R301-T	-	-	.044"	764	.46	WAL 710/636 - TABLE IV

*The figure of merit is determined from the formula $\frac{V_{SUB}}{V_{HAD}}$ where

V_{SUB} is the ballistic limit of the sample tested and V_{HAD} is the characteristic ballistic limit of an equivalent weight of Hadfield manganese steel.

APPENDIX B

TABLE XI

Average Figures of Merit for Various Alloys Under Impact of

Cal. .45 (Steel-Jacketed) Ball Projectiles

(Reference - Table IX)

Type Alloy	No. Samples	Average Merit Figure
24S-RT	1	.830
75S-T	12	.813
R301-T	2	.790
24S-T	3	.783
Alclad 24S-T	2	.780
14S-W	1	.780
R301-W	3	.753

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TABLE XII

Average Figures of Merit for Various Alloys

Under Impact of Cal. .22 Fragment-Simulating Projectiles, G-2

(Reference - Table X)

Type Alloy	No. Samples	Average Merit Figure
24S-RT	1	.590
Alclad 24S-T	3	.527
14S-W	1	.510
R301-W	3	.493
24S-T	3	.493
75S-T	7	.487
R301-T	2	.465

APPENDIX C

NICKEL ALLOYS

APPENDIX C

TABLE I

Summary of Results of Tests for Resistance to Perforation

Conducted at Watertown Arsenal on Samples of Various Alloys of

Nickel in Various Conditions of Hardness

Sample No.	Alloy	Condition	Hardness Rockwell	Hardness Equivalent BHN	Act. Gauge	Equiv. Steel Gauge	Ballistic Limit Cal. .45[1]	Ballistic Limit G-2[2]
AK-1	K Monel	Annealed	69 Rb	121	.043"	--	593	--
AK-2	"	"	68 Rb	120	.043"	--	572	--
AK-3	"	"	70 Rb	123	.044"	--	--	1223
AK-4	"	"	69 Rb	121	.044"	--	--	1245
AK-5	"	"	69 Rb	121	.044"	--	--	--
AK-6	"	"	69 Rb	121	.044"	.050"	--	--
BK-1	K Monel	Annealed and age hardened	28 Rc	277	.046"	--	533	--
BK-2	"	"	29 Rc	285	.044"	--	626	--
BK-3	"	"	29 Rc	285	.045"	--	--	1208
BK-4	"	"	28 Rc	277	.045"	.050"	--	1260
BK-5	"	"	28 Rc	277	.044"	--	--	--
BK-6	"	"	28 Rc	277	.045"	--	--	--
CK-1	K Monel	Cold rolled ¼ hard	93 Rb	201	.043"	--	436	--
CK-2	"	"	93 Rb	201	.042"	--	492	--
CK-3	"	"	93 Rb	201	.044"	.049"	--	1110
CK-4	"	"	93 Rb	201	.044"	--	--	1130
CK-5	"	"	93 Rb	201	.044"	--	--	--
CK-6	"	"	93 Rb	201	.044"	--	--	--

[1]Cal. .45 steel-jacketed ball projectile - 230 grains.

[2]Cal. .22 flak-simulating projectile, G-2 - 17 grains.

APPENDIX C

TABLE I (CONT'D)

Sample No.	Alloy	Condition	Hardness Rockwell	Hardness Equivalent BHN	Act. Gauge	Equiv. Steel Gauge	Ballistic Limit Cal. .45[1]	Ballistic Limit G-2[2]
DK-1	K Monel	Cold rolled ¼ hard and age hardened	34 Rc	330	.044"	--	650	--
DK-2	"	"	34 Rc	330	.045"	--	527	--
DK-3	"	"	34 Rc	330	.044"	--	--	1152
DK-4	"	"	34 Rc	330	.044"	.049"	--	1125
DK-5	"	"	35 Rc	339	.043"	--	--	--
DK-6	"	"	34 Rc	330	.044"	--	--	--
EK-1	K Monel	Cold rolled ½ hard	98 Rb	229	.043"	--	494	--
EK-2	"	"	98 Rb	229	.042"	--	<462	--
EK-3	"	"	99 Rb	240	.043"	--	--	968
EK-4	"	"	100 Rb	250	.043"	.048"	--	975
EK-5	"	"	100 Rb	250	.043"	--	--	--
EK-6	"	"	99 Rb	240	.043"	--	--	--
FK-1	K Monel	Cold rolled ½ hard and age hardened	34 Rc	330	.044"	--	529	--
FK-2	"	"	35 Rc	339	.045"	--	558	--
FK-3	"	"	36 Rc	349	.043"	--	--	1043
FK-4	"	"	35 Rc	339	.044"	.049"	--	1093
FK-5	"	"	35 Rc	339	.043"	--	--	--
FK-6	"	"	35 Rc	339	.043"	--	--	--
GK-1	K Monel	Cold rolled full hard	102 Rb	264	.043"	--	<455	--
GK-2	"	"	103 Rb	274	.043"	--	444	--
GK-3	"	"	103 Rb	274	.043"	--	--	900
GK-4	"	"	102 Rb	264	.043"	--	--	938
GK-5	"	"	102 Rb	264	.043"	.048"	--	--
GK-6	"	"	102 Rb	264	.043"	--	--	--

APPENDIX C

TABLE I (CONT'D)

Sample No.	Alloy	Condition	Hardness Rockwell	Hardness Equivalent BHN	Act. Gauge	Equiv. Steel Gauge	Ballistic Limit Cal. .45[1]	Ballistic Limit G-2[2]
DZ-1	Z Nickel	Cold rolled ¼ hard and age hardened	38 Rc	367	.043"	--	<340	--
DZ-2	"	"	39 Rc	379	.043"	--	359	--
DZ-3	"	"	39 Rc	379	.043"	--	--	775
DZ-4	"	"	38 Rc	367	.042"	--	--	862
DZ-5	"	"	38 Rc	367	.042"	--	--	--
DZ-6	"	"	38 Rc	367	.042"	.048"	--	--
EZ-1	Z Nickel	Cold rolled ½ hard	27 Rc	269	.044"	--	460	--
EZ-2	"	"	27 Rc	269	.045"	--	450	--
EZ-3	"	"	27 Rc	269	.044"	--	--	998
EZ-4	"	"	28 Rc	277	.043"	--	--	1037
EZ-5	"	"	27 Rc	269	.043"	--	--	--
EZ-6	"	"	27 Rc	269	.042"	.048"	--	--
FZ-1	Z Nickel	Cold rolled ½ hard and age hardened	36 Rc	349	.043"	--	413	--
FZ-2	"	"	35 Rc	339	.043"	--	480	--
FZ-3	"	"	35 Rc	339	.043"	--	--	872
FZ-4	"	"	36 Rc	349	.044"	--	--	933
FZ-5	"	"	34 Rc	330	.043"	.048"	--	--
FZ-6	"	"	35 Rc	339	.043"	--	--	--
GZ-1	Z Nickel	Cold rolled full hard	34 Rc	330	.044"	--	422	--
GZ-2	"	"	35 Rc	339	.043"	--	372	--
GZ-3	"	"	34 Rc	330	.044"	--	--	905
GZ-4	"	"	34 Rc	330	.045"	--	--	888
GZ-5	"	"	34 Rc	330	.043"	--	--	--
GZ-6	"	"	35 Rc	339	.044"	.049"	--	--

APPENDIX C

TABLE I (CONT'D)

Sample No.	Alloy	Condition	Hardness: Rockwell	Hardness: Equivalent BHN	Act. Gauge	Equiv. Steel Gauge	Ballistic Limit: Cal. .45[1]	Ballistic Limit: G-22[2]
HK-1	K Monel	Cold rolled full hard and age hardened	40 Rc	[illegible]	.045"	--	549	--
HK-2	"	"	39 Rc	379	.045"	--	467	--
HK-3	"	"	41 Rc	395	.043"	.049"	--	1062
HK-4	"	"	39 Rc	379	.044"	--	--	1000
HK-5	"	"	39 Rc	379	.044"	--	--	--
HK-6	"	"	40 Rc	[illegible]	.043"	--	--	--
AZ-1	Z Nickel	Annealed	77 Rb	139	.044"	--	635	--
AZ-2	"	"	77 Rb	[illegible]	.044"	--	653	--
AZ-3	"	"	78 Rb	141	.044"	--	--	1230
AZ-4	"	"	78 Rb	141	.044"	--	--	1275
AZ-5	"	"	78 Rb	141	.044"	.049"	--	--
AZ-6	"	"	78 Rb	141	.043"	--	--	--
BZ-1	Z Nickel	Annealed and age hardened	34 Rc	330	.043"	--	<397	--
BZ-2	"	"	34 Rc	330	.043"	--	362	--
BZ-3	"	"	34 Rc	330	.044"	--	--	[illegible]
BZ-4	"	"	34 Rc	330	.044"	--	--	902
BZ-5	"	"	35 Rc	339	.043"	.049"	--	--
BZ-6	"	"	35 Rc	339	.044"	--	--	--
CZ-1	Z Nickel	Cold rolled ¼ hard	20 Rc	225	.043"	--	477	--
CZ-2	"	"	20 Rc	225	.043"	--	457	--
CZ-3	"	"	20 Rc	225	.043"	--	--	1109
CZ-4	"	"	20 Rc	225	.043"	--	--	1118
CZ-5	"	"	19 Rc	220	.043"	.049"	--	--
CZ-6	"	"	19 Rc	220	.042"	--	--	--

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TABLE I (CONT'D)

Sample No.	Alloy	Condition	Hardness Rockwell	Hardness Equivalent BHN	Act. Gauge	Equiv. Steel Gauge	Ballistic Limit Cal. .45[1]	Ballistic Limit [illegible]
EZM-1	Mod. Z	Cold rolled ½ hard	27 Rc	269	.044"	--	554	--
EZM-2	Nickel	"	28 Rc	277	.043"	--	549	--
EZM-3	"	"	31 Rc	302	.04[illegible]"	--	--	1238
EZM-4	"	"	31 Rc	302	.044"	--	--	1167
EZM-5	"	"	32 Rc	311	.044"	--	--	--
EZM-6	"	"	29 Rc	285	.043"	.047"	--	--
FZM-1	Mod. Z	Cold rolled ½ hard and age hardened	42 Rc	406	.044"	--	636	--
FZM-2	Nickel	"	41 Rc	396	.04[illegible]"	--	643	--
FZM-3	"	"	41 Rc	396	.043"	--	--	1232
FZM-4	"	"	42 Rc	406	.043"	--	--	1250
FZM-5	"	"	41 Rc	396	.044"	--	--	--
FZM-6	"	"	42 Rc	406	.043"	.048"	--	--
GZM-1	Mod. Z	Cold rolled full hard	36 Rc	349	.044"	--	457	--
GZM-2	Nickel	"	36 Rc	349	.045"	--	434	--
GZM-3	"	"	37 Rc	358	.044"	--	--	1060
GZM-4	"	"	37 Rc	358	.046"	--	--	1037
GZM-5	"	"	36 Rc	349	.044"	--	--	--
GZM-6	"	"	37 Rc	358	.045"	.047"	--	--
HZM-1	Mod. Z	Cold rolled full hard and age hardened	45 Rc	435	.044"	--	610	--
HZM-2	Nickel	"	45 Rc	435	.043"	--	581	--
HZM-3	"	"	45 Rc	435	.043"	--	--	1188
HZM-4	"	"	45 Rc	435	.044"	--	--	1236
HZM-5	"	"	45 Rc	435	.045"	--	--	--
HZM-6	"	"	44 Rc	425	.045"	.048"	--	--

APPENDIX C

TABLE I (CONT'D)

Sample No.	Alloy	Condition	Hardness Rockwell	Hardness Equivalent BHN	Act. Gauge	Equiv. Steel Gauge	Ballistic Limit Cal. .45[1]	Ballistic Limit G-2[2]
HZ-1	Z Nickel	Cold rolled full hard and age hardened	41 Rc	396	.043"	--	380	--
HZ-2	"	"	41 Rc	396	.044"	--	397	--
HZ-3	"	"	41 Rc	396	.043"	--	--	878
HZ-4	"	"	42 Rc	406	.044"	--	--	1005
HZ-5	"	"	41 Rc	396	.044"	--	--	--
HZ-6	"	"	41 Rc	396	.044"	.050"	--	--
AZM-1	Mod. Z Nickel	Annealed	82 Rb	153	.045"	--	648	--
AZM-2	"	"	81 Rb	150	.044"	--	783	--
AZM-3	"	"	81 Rb	150	.043"	--	--	1373
AZM-4	"	"	78 Rb	141	.044"	--	--	1530
AZM-5	"	"	80 Rb	147	.045"	.048"	--	--
AZM-6	"	"	82 Rb	153	.045"	--	--	--
BZM-1	Mod. Z Nickel	Annealed and age hardened	35 Rc	339	.045"	--	758	--
BZM-2	"	"	35 Rc	339	.044"	--	784	--
BZM-3	"	"	36 Rc	349	.043"	--	--	1326
BZM-4	"	"	35 Rc	339	.042"	--	--	1273
BZM-5	"	"	36 Rc	349	.044"	.046"	--	--
BZM-6	"	"	36 Rc	349	.043"	--	--	--
CZM-1	Mod. Z Nickel	Cold rolled ¼ hard	22 Rc	238	.043"	--	650	--
CZM-2	"	"	21 Rc	232	.044"	--	602	--
CZM-3	"	"	21 Rc	232	.045"	--	--	1252
CZM-4	"	"	20 Rc	226	.043"	--	--	1325
CZM-5	"	"	22 Rc	238	.043"	.046"	--	--
CZM-6	"	"	26 Rc	262	.044"	--	--	--
DZM-1	Mod. Z Nickel	Cold rolled ¼ hard and age hardened	38 Rc	367	.042"	--	592	--
DZM-2	"	"	39 Rc	379	.042"	--	668	--
DZM-3	"	"	39 Rc	379	.044"	--	--	1345
DZM-4	"	"	39 Rc	379	.051"	--	--	1700
DZM-5	"	"	39 Rc	379	.042"	--	--	1281
DZM-6	"	"	39 Rc	379	.043"	.046"	--	--

APPENDIX C

TABLE II

Summary of Physical Tests Conducted at Huntington, W. Va.,

Laboratory of International Nickel Company

Alloy	Condition	Yield Strength P.S.I.	Tensile Strength P.S.I.	Elongation %
K	Annealed	37,600	100,000	38
K	Annealed and Age Hardened	105,000	169,000	18
K	Cold Rolled ¼ Hard	93,800	116,000	20
K	Cold Rolled ¼ Hard and Age Hardened	132,000	181,000	14
K	Cold Rolled ½ Hard	121,000	129,000	5
K	Cold Rolled ½ Hard and Age Hardened	139,000	184,000	11
K	Cold Rolled Full Hard	136,000	147,000	4
K	Cold Rolled Full Hard and Age Hardened	143,000	195,000	9
Z	Annealed	44,300	103,600	35
Z	Annealed and Age Hardened	123,000	158,000	10
Z	Cold Rolled ¼ Hard	97,300	120,700	24
Z	Cold Rolled ¼ Hard and Age Hardened	146,000	172,000	8
Z	Cold Rolled ½ Hard	130,500	148,000	6
Z	Cold Rolled ½ Hard and Age Hardened	154,000	175,000	8
Z	Cold Rolled Full Hard	163,700	180,000	3
Z	Cold Rolled Full Hard and Age Hardened	170,000	194,000	3
Mod. Z	Annealed	56,500	114,000	48
Mod. Z	Annealed and Age Hardened	112,400	170,600	25
Mod. Z	Cold Rolled ¼ Hard	107,800	131,000	23
Mod. Z	Cold Rolled ¼ Hard and Age Hardened	139,200	187,700	14
Mod. Z	Cold Rolled ½ Hard	124,700	154,600	12.5
Mod. Z	Cold Rolled ½ Hard and Age Hardened	153,400	196,100	11.5
Mod. Z	Cold Rolled Full Hard	161,400	193,700	3
Mod. Z	Cold Rolled Full Hard and Age Hardened	200,000	230,700	8

APPENDIX D

FABRICS

REFERENCES

(Applicable to APPENDIX D)

1. O.O. 423/98 - Wtn. 423/161, 17 December 1943.

2. O.O. 423/121 - Wtn. 423/169, 14 February 1944.

3. O.O. 423/7544 - Wtn. 400.112/3053, 3 March 1944.

4. O.O. 426/1580 - Wtn. 426/275, 14 March 1944.

5. O.O. 426/2009 - Wtn. 426/284, 29 March 1944.

6. O.O. 400.112/6295 - Wtn. 400.112/3062, 3 April 1944.

7. O.O. 400.112/12514 - Wtn. 400.112/3061, 6 April 1944.

8. O.O. 423/7754 - Wtn. 400.112/3083, 13 April 1944.

9. O.O. 400.112/6902 - Wtn. 400.112/3097, 29 April 1944.

10. O.O. 423/7842 - Wtn. 423/177, 8 May 1944.

11. O.O. 423/7881 - Wtn. 400.112/3573, 19 May 1944.

12. O.O. 423/7893 - Wtn. 423/179, 22 May 1944.

13. O.O. 400.112/6883 - Wtn. 400.112/3096, 29 May 1944.

14. O.O. 400.112/9391 - Wtn. 400.112/3163, 4 August 1944.

15. Report No. WAL 710/540. "Resistance of Unsized 19-Ounce Nylon Duck to Perforation by Fragment-Simulating Projectiles." J. F. Sullivan, 29 August 1944.

16. Report No. WAL 710/596. "Resistance to Perforation by 34-Grain Fragment-Simulating Projectile, G-1-S, of Various Numbers of Layers of 17-1/2 Ounces Nylon Duck." J. F. Sullivan, 17 March 1944.

17. Report No. WAL 710/610. "Effect of Quilting Upon the Resistance to Perforation of Fiber Glass ECC-11-162." J. F. Sullivan, 20 April 1944.

18. Report No. WAL 710/613. "Resistance of 6-Ply Glass Webbing to Perforation by Various Small Arms Projectiles." J. F. Sullivan, 20 April 1944.

19. Report No. WAL 710/614. "Resistance of Two Types of Nylon Belting to Perforation by Various Small Arms Projectiles." J. F. Sullivan, 21 April 1944.

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20. Report No. WAL 710/616. "Resistance of Various Layers of 17-1/2 Ounce Nylon to Several Types of Small Arms Projectiles." J. F. Sullivan, 22 April 1944.

21. Report No. WAL 710/649. "Resistance of 7-Ply Silk Webbing to Perforation by Fragment-Simulating Projectiles." J. F. Sullivan, 3 June 1944.

22. Report No. WAL 710/653. "Resistance of Various Samples of Fiberglas to Perforation by Fragment-Simulating Projectiles." J. F. Sullivan, 10 June 1944.

23. Report No. WAL 710/659. "Resistance of Weinberger Protective Fabric and of Its Components to Perforation by Fragment-Simulating Projectiles." J. F. Sullivan, 30 June 1944.

24. Report No. WAL 710/660. "Resistance of Nylon Parachute Cloth to Perforation by Fragment-Simulating Projectiles." J. F. Sullivan, 1 July 1944.

25. Report No. WAL 762/247. "Development of Projectiles, to Be Used in Testing Body Armor, to Simulate Flak and 20 mm. HE Fragments." J. F. Sullivan, 17 December 1943.

26. Report No. WAL 762/253. "Development of a Projectile to Be Used in Testing Body Armor, to Simulate Fragments of a 20 mm. HE Projectile." J. F. Sullivan, 7 January 1944.

27. Report No. WAL 762/314. "Comparison of G-2 Projectiles of Various Manufacture." J. F. Sullivan, 23 May 1945.

APPENDIX D

TABLE I
(Reference Report No. WAL 710/616)

Summary of Ballistic Tests Conducted at Watertown Arsenal
on Various Multi-Layered Assemblies of 17 1/2 Ounce Nylon Duck

Sample	Equivalent Steel Gauge	Ballistic Limits G-1-A[1]	G-1-S[2]	G-2[3]	.45[4]
Stretched tautly across a wooden ballistic frame-back unsupported:					
6 Plies Nylon Duck	.022"	----	790	----	----
7 Plies Nylon Duck	.026"	513	844	1095	----
8 Plies Nylon Duck	.029"	498	938	1105	----
9 Plies Nylon Duck	.033"	550	946	----	500
10 Plies Nylon Duck	.037"	545	981	1215	675
11 Plies Nylon Duck	.040"	567	1058	1310	704
12 Plies Nylon Duck	.044"	566	1105	1360	750
150 Plies Nylon Parachute Cloth	.045"	----	----	1467	698
11 Plies #8 Cotton Duck	.047"	----	----	----	395
17 Plies Fiber Glass ECC-11-162 Plus 5 Plies Nylon Duck	.045"	----	----	1208	766
Hadfield Manganese Steel (Average)	.044"	----	1050	1660	940
Strapped on sawdust-filled canvas dummy:					
6 Plies Nylon Duck	.022"	----	865	----	----
7 Plies Nylon Duck	.026"	----	948	1064	----
8 Plies Nylon Duck	.029"	----	972	1081	----
9 Plies Nylon Duck	.033"	----	1020	----	----
10 Plies Nylon Duck	.037"	----	1063	1207	----
11 Plies Nylon Duck	.040"	----	1090	1360	----
12 Plies Nylon Duck	.044"	----	1102	----	----
11 Plies #8 Cotton Duck	.047"	----	----	883	----
23 Plies Fiber Glass ECC-11-162	.045"	----	----	1189	----

1. Cal. .30 (150 grains)
2. Cal. .30 (54 grains)
3. Cal. .22 (17 grains)
4. Standard Cal. .45 ball ammunitions.

APPENDIX D

TABLE II
(Reference Report No. WAL 710/596)

Comparison of Ballistic Limits of Various Numbers of Layers of 17-1/2 Ounce Nylon Duck, as Rigidly Mounted, and as Loosely Mounted with Those of Hadfield Manganese Steel of Equivalent Weight

Number of Layers	Equivalent Steel Thickness	Ballistic Limit with 34-Grain Fragment-Simulating Projectile G-1-S		
		Rigid	Loose	Steel of Equivalent Weight
6	.022	790	865	----
7		844	948	----
8		938	972	----
9	.033	946	1020	----
10		981	1063	----
11		1058	1090	880
12	.044	1105	1102	1020

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TABLE III
(Reference Report No. WAL 710/540)

Comparison of Resistance Characteristics of Unsized 19-Ounce Nylon Duck with Those of Sized 17-1/2-Ounce Nylon Duck

Material	Plies	Equivalent Steel Gauge	Ballistic Limit F/S Cal. .45[1]	Ballistic Limit F/S G-2[2]
17-1/2-Ounce, Sized	9	.033"	500	----
19-Ounce, Unsized	11	.036"	627	1260
17-1/2-Ounce, Sized	10	.037"	675	1215
19-Ounce, Unsized	12	.039"	629	1283
17-1/2-Ounce, Sized	11	.040"	704	1310
19-Ounce, Unsized	13	.043"	685	1309
17-1/2-Ounce, Sized	12	.044"	750	1360
19-Ounce, Unsized	14	.046"	688	1350

1. Cal. .45 steel-jacketed ball projectile - 230 grains.

2. Cal. .22 fragment-simulating projectile - 17 grains.

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TABLE IVa
(Reference Report No. WAL 710/660)

Summary of Penetration Tests Conducted at Watertown Arsenal on Samples of Nylon Parachute Cloth

Sample	Equivalent Steel Gauge	Ballistic Limit (F/S)	
		G-2[1]	Cal. .45[2]
NFD-168/3	.044"	1370	676
NFD-170	.044"	1435	656
NFD-172	.044"	1435	712
For Comparison:			
17-1/2 oz. Nylon Duck	.044"	1360	750

1. Cal. .22 fragment-simulating projectile - 17 grains.

2. Cal. .45 (steel-jacketed) ball projectile - 230 grains.

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TABLE IVb
(Reference Report No. WAL 710/660)

Data Concerning Three Samples of Nylon Parachute Cloth
as Reported by E. I. DuPont de Nemours and Company

	DuPont Style Number		
	NFD-170	NFD-168/3	NFD-172
Yarn Type	Bright High Tenacity	Bright High Tenacity	Bright High Tenacity
Yarn Count: Warp Filling	70-23-5 70-23-5	70-23-7 70-23-7	105-34-5 105-34-5
Weave	Cargo	2 x 1 Twill Rip-Stop	Taffeta
Construction (loom count)	80 x 84	84 x 92	60 x 64
Reed	4012	4212	3012
Reed Width	40"	40.9"	40"
Pickwheel	84	90	64
Finisher	Huguet	Huguet	Huguet
Finished Construction	90 x 88	96 x 98	68 x 67
Finished Width	35-1/8"	36"	34-3/4"
Porosity	115	128	81
Thickness	0.0055"	0.0056"	0.0062"
Weight (oz./sq.yd.)	1.83	2.00	2.04
Tensile Strength (1" strip)	94x86 lbs.	99x98 lbs.	111x104 lbs.
Tear (Tongue)	6.8x7.2 lbs.	12.7x12.1 lbs.	9.6x9.4 lbs.
Tear (Trapezoid)	14.3x16.7 lbs.	-----	29.5x27.0 lbs.
Elongation	26 x 38%	25 x 32%	23 x 45%

APPENDIX D

TABLE V

(Reference Report No. WAL 710/614)

Summary of Ballistic Tests Conducted at Watertown Arsenal on Two Types of Nylon Belting Designated 63-2831 and 63-2831A

Sample	Equivalent Steel Gauge	G-1-A[1]	G-1-S[2]	G-2[3]	.45[4]
Stretched tautly across a wooden ballistic frame-back unsupported:					
63-2831	.040"	484	840	973	517
63-2831A	.041"	496	791	1053	537
11 Plies Nylon Duck (17-1/2 oz.)	.040"	567	1058	1310	704
Hadfield Steel (Average)	.040"	—	900	1600	900
Strapped to sawdust-filled canvas dummy:					
63-2831	.040"	500	896	1075	—
63-2831	.041"	—	806	1085	—
11 Plies Nylon Duck (17-1/2 oz.)	.040"	—	1090	1360	—

1. Cal. .30 (150 grains)
2. Cal. .30 (34 grains)
3. Cal. .22 (17 grains)
4. Standard Cal. .45 ball ammunition

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TABLE VI
(Reference Report No. WAL 710/610)

Summary of Ballistic Tests Conducted at Watertown Arsenal on Various Assemblies of Fibre Glass ECC-11-162

Test Sample	Quilting Interval	Equivalent Steel Gauge	Ballistic Limit: G.2 (Cal. .22, 17 Grains)	Ballistic Limit: Standard Cal. .45 Ball
Tautly stretched on rigid wooden frame - back unsupported:				
21 Plies Fiber Glass Plus 1 Ply Nylon Duck	8"	.045"	1130	711
"	4"	.045"	1148	729
"	1"	.045"	1173	738
"	1/2"	.045"	1138	697
23 Plies Fiber Glass	2"	.045"	——	710
17 Plies Fiber Glass Plus 3 Plies Nylon Duck	2"	.045"	1208	760
23 Plies Fiber Glass Plus 1 Ply Nylon Duck	2"	.049"	1290	——
21 Plies Fiber Glass Plus 3 Plies Nylon Duck	2"	.053"	1335	836
12 Plies Nylon Duck	11"	.044"	1560	750
Hadfield Manganese Steel (Average)	--	.044"	1660	940
Strapped to sawdust-filled canvas dummy:				
23 Plies Fiber Glass	2"	.045"	1189	——
23 Plies Fiber Glass Plus 1 Ply Nylon Duck	2"	.049"	1238	——
11 Plies Nylon Duck	11"	.020"	1360	——

APPENDIX D

TABLE VIIa
(Reference Report No. WAL 710/658)

Summary of Ballistic Tests Conducted at Watertown Arsenal on Various Samples of "Fiberglas" submitted by Owens-Corning Fiberglas Corporation

Sample	No. of Plies	Equivalent Steel Gauge	Ballistic Limit (F/S) Cal. .45[1]	G-2[2]
ECC-112	107	.044"	698	1056
ECC-113	96	.044" -	625	1101
ECC-115	94	.044"	588	1080
ECC-116	75	.044"	698	1082
ECC-117	79	.044"	671	974
ECC-127	58	.044"	647	1082
ECC-128	45	.044"	595	1090
ECC-158	32	.044"	694	1154
ECC-158a	32	.044"	738	1108
ECC-161	18	.044"	782	1188
ECC-162	19	.044"	618	956
X-1549	1.	.044"	669	1022
X-1581	39	.044"	549	988
For Comparison:				
17-1/2 Ounce Nylon Duck	12	.044"	750	1560
Hadfield Manganese Steel (Average)		.044"	940	1680

1. Cal. .45 (steel-jacketed) ball projectiles - 230 grains.
2. Cal. .22 fragment-simulating projectile - 17 grains.

APPENDIX D

TABLE VIIb
(Reference Report No. WAL 710/853)

Physical Properties of Fiberglas Samples as Reported by
Owens-Corning Fiberglas Corporation

Fabric #	Weight ozs. Sq.Yd.	Thickness Inches MM	Ends Per Inch	Picks per Inch	Weave	Warp Yarn	Fill Yarn	Break Str. Lbs./" Warp	Break Str. Lbs./" Fill
ECC-112	2.3	.003	40	39	Plain	450-1/2-5 TPI	450-1/2-5 TPI	110	105
ECC-115	2.5	.004	48	48	"	225-1/0-1½ TPI	225-1/0-1½ TPI	115	120
ECC-116	3.4	.004	60	58	"	450-1/2-5 TPI	450-1/2-5 TPI	160	145
ECC-117	3.3	.004	64	62	"	225-1/0-1½ TPI	225-1/0-1½TPI	140	140
ECC-127	6.4	.007	42	32	"	450-3/2-5 TPI	450-3/2-5 TPI	380	300
ECC-128	6.2	.007	42	32	"	225-1/3-5 TPI	225-1/3-5 TPI	325	250
ECC-158	7.0	.008	64	60	Crow	450-2/2-5 TPI	450-2/2-5 TPI	375	330
ECC-161	14.1	.015	28	16	Plain	450-4/5-5 TPI	450-4/5-5 TPI	700	460
ECC-162	12.0	.015	28	16	"	225-2/5-5 TPI	225-2/5-5 TPI	675	420
X-1549	17.2	.020	21	18	"	225-4/4-5 TPI	225-4/4-5 TPI	770	780
X-1581	5.8	.007	39	54	"	225-1/3-5 TPI	225-1/3-5 TPI	280	250

APPENDIX D

TABLE VIIc
(Reference Report No. WAL 710/653)

Correlation Between Resistance to Perforation of Fiberglas Samples and Their Yarn and Texture Characteristics

Ballistic Limit (F/S)	Sample	Ends per Inch	Yarn
Cal. .45 (steel-jacketed) Ball Projectiles:			
549	X-1581	59	225-1/3-5 TPI
588	ECC-115	48	225-1/0-1½ TPI
593	ECC-128	42	225-1/3-5 TPI
618	ECC-162	28	225-2/5-5 TPI
647	ECC-127	42	450-3/2-5 TPI
669	X-1549	21	225-4/4-5 TPI
671	ECC-117	64	225-1/0-1½ TPI
698	ECC-112	40	450-1/2-5 TPI
698	ECC-116	60	450-1/2-5 TPI
732	ECC-161	28	450-4/5-5 TPI
738	ECC-158	64	450-2/2-5 TPI
Cal. .22 Fragment-Simulating Projectiles:			
956	ECC-162	28	225-2/5-5 TPI
974	ECC-117	64	225-1/0-1½ TPI
988	X-1581	59	225-1/3-5 TPI
1022	X-1549	21	225-4/4-5 TPI
1030	ECC-115	48	225-1/0-1½ TPI
1056	ECC-112	40	450-1/2-5 TPI
1062	ECC-116	60	450-1/2-5 TPI
1082	ECC-127	42	450-3/2-5 TPI
1090	ECC-128	42	225/1/3-5 TPI
1108	ECC-158	64	450/2/2-5 TPI
1188	ECC-161	28	450-4/5-5 TPI

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TABLE VIII
(Reference Report No. WAL 710/613)

Summary of Ballistic Tests Conducted at Watertown Arsenal on 6-Ply Glass Webbing Submitted by Russell Manufacturing Company

Sample Tested	Equivalent Steel Thickness	Ballistic Limit G-1-S[1]	G-1-A[2]	G-2[3]	.45[4]
Tautly stretched on rigid wooden frame-back unsupported:					
Glass webbing (6-ply)	.079"	1121	691	1300	786
Nylon Duck (12-ply)	.044"	1105	566	1360	750
Hadfield Steel (Average)	.044"	1050	475	1660	940
Strapped on sawdust-filled canvas dummy:					
Glass Webbing (6-ply)	.079"	1175	—	1360	—
Nylon Duck (11-ply)	.040"	1090	—	1360	—

1. Cal. .30 (34 grain)
2. Cal. .30 (150 grain)
3. Cal. .22 (17 grain)
4. Standard Cal. .45 ball ammunition (steel-jacketed 230 grains)

APPENDIX D

TABLE IX
(Reference Report No. WAL 710/649)

Summary of Ballistic Tests Conducted at Watertown Arsenal on Samples of 7-Ply Silk Webbing Supplied by Russell Manufacturing Company

Sample Tested	Steel Thickness	Ballistic Limit (F/S)	
		Cal. .45[1]	G-2[2]
Silk Webbing (7-Ply)	.042"	724	1336
Nylon Webbing	.041"	537	1055
Nylon Duck (12-Ply)	.044"	750	1360
Glass Webbing (6-Ply)	.079"	786	1300
Hadfield Steel (Average)	.042"	920	1630

1. Caliber .45 (steel-jacketed) ball projectile - 230 grains.

2. Caliber .22 fragment-simulating projectile - 17 grains.

APPENDIX D

TABLE X
(Reference Report No. WAL 710/659)

Summary of Penetration Tests Conducted at Watertown Arsenal on Samples of Weinberger Protective Fabric and Its Components

Sample	Equivalent Steel Gauge	Ballistic Limits (F/S)			
		G-1-A[1]	G-1-S[2]	G-2[3]	Cal. .45[4]
Complete Assembly	.040"	488	961	1108	560
4 Plies Corded Component	.046"	---	---	1044	505
3 Plies Corded Component	.034"	---	---	990	474
3 Plies Corded Component (coated with rubber)	.046"	---	---	1028	---
4 Plies Quilting	.068"	---	---	---	735
3 Plies Quilting	.051"	---	---	---	694
2 Plies Quilting	.034"	---	---	1080	613
1 Ply Quilting	.017"	---	---	804	460
For Comparison:					
11 Plies 17½ oz. Nylon Duck	.040"	567	1058	1310	704
Hadfield Manganese Steel	.040"	---	900	1600	900

1. Cal. .30 fragment-simulating projectile - 150 grains.
2. Cal. .30 fragment-simulating projectile - 54 grains.
3. Cal. .22 fragment-simulating projectile - 17 grains.
4. Cal. .45 (steel-jacketed) ball projectile - 230 grains.

APPENDIX D

TABLE XI

Comparative Resistance to Perforation by Cal. .45 Ball Projectiles of Various Fabric Samples

Material	Equiv. Steel Gauge	Cal. .45 Ballistic Limit	Cal. .45 Figure of Merit*	Reference
11 plies #8 Cotton Duck	.047"	395	41	Table I
4 plies corded component of Weinberger Prot. Fabric	.046"	505	56	Table X
Nylon Belting	.040"	517	57	Table V
Fiberglas (X-1581)	.044"	549	58	Table VIIa
Nylon Belting	.041"	537	59	Table V
Weinberger Protective Fabric	.040"	560	62	Table X
Fiberglas (ECC-115)	.044"	588	63	Table VIIa
Fiberglas (ECC-128)	.044"	593	63	Table VIIa
Fiberglas (ECC-113)	.044"	623	66	Table VIIa
Fiberglas (ECC-162)	.044"	618	66	Table VIIa
Fiberglas (ECC-127)	.044"	647	69	Table VIIa
3 plies quilted component of Weinberger Prot. Fabric	.051"	694	69	Table X
Nylon Parachute Cloth	.044"	656	70	Table IVa
19 ounce unsized Nylon Duck (12 plies)	.039"	629	71	Table III
Fiberglas (ECC-117)	.044"	671	71	Table VIIa
Fiberglas (X-1549)	.044"	669	71	Table VIIa
19 ounce unsized Nylon Duck (14 plies)	.046"	688	72	Table III
Nylon Parachute Cloth	.044"	676	72	Table IVa
Nylon Parachute Cloth	.045"	698	73	Table I
21 plies Fiberglas (Ecc-11-162), plus 1 ply 17½ oz. Nylon Duck with ½" quilting	.045"	697	73	Table VI
19 ounce unsized Nylon Duck (13 plies)	.043"	685	74	Table III
Fiberglas (ECC-112)	.044"	698	74	Table VIIa
Fiberglas (ECC-116)	.044"	698	74	Table VIIa
Fiberglas (ECC-138)	.044"	[illegible]	74	Table VIIa

APPENDIX D

TABLE XI (CONT'D)

Material	Equiv. Steel Gauge	Cal. .45 Ballistic Limit	Cal. .45 Figure of Merit*	Reference
21 plies Fiberglas (ECC-162) plus 1 ply 17½ oz. Nylon Duck with 8-inch quilting	.045*	711	75	Table VI
23 plies Fiberglas (ECC-162) with 2" quilting	.045	710	75	Table VI
Nylon Parachute Cloth	.044*	712	76	Table [illegible]
21 plies Fiberglas (ECC-162) plus 1 ply 17½ oz. Nylon Duck with 4-inch quilting	.045*	729	77	Table VI
21 plies Fiberglas (ECC-162) plus 1 ply 17½ oz. Nylon Duck with 1-inch quilting	.045*	738	78	Table VI
11 plies sized 17½ oz. Nylon Duck	.040*	704	78	Table I
Fiberglas (ECC-161)	.044*	732	78	Table VIIa
Fiberglas (ECC-138)	.044*	738	79	Table VIIa
Silk Webbing	.042*	724	79	Table IX
12 plies sized 17½ ounce Nylon Duck	.044*	750	80	Table I
17 plies Fiberglas (ECC-162) plus 3 plies sized 17½ ounce Nylon Duck	.045*	766	80	Table VI

*Figure of merit determined by this formula: $\frac{V_{SUB}}{V_{HAD}} \times 100$ where V_{SUB} is the ballistic limit of the subject sample and V_{HAD} is the characteristic ballistic limit of an equivalent weight of Hadfield manganese steel.

APPENDIX D

TABLE XII

Comparative Resistance to Perforation by

Cal. .22 Fragment-Simulating Projectiles of Various Fabric Samples

Material	Equiv. Steel Gauge	Cal. .22 Ballistic Limit	Cal. .22 Figure of Merit*	Reference
11 plies #8 Cotton Duck	.047"	853**	52	Table I
Fiberglas (ECC-162)	.044"	956	58	Table VIIa
Fiberglas (ECC-117)	.044"	974	59	Table VIIa
Fiberglas (ECC-158)	.044"	988	60	Table VIIa
Nylon Belting	.040"	973	61	Table V
3 plies of corded component of Weinberger Prot. Fabric Coated with Fabric	.046"	1028	61	Table X
4 plies of corded component of Weinberger Prot. Fabric	.046"	1044	62	Table X
Fiberglas (ECC-115)	.044"	1030	62	Table VIIa
Fiberglas (E-1549)	.044"	1022	62	Table VIIa
Fiberglas (ECC-112)	.044"	1036	62	Table VIIa
Fiberglas (ECC-116)	.044"	1062	64	Table VIIa
Fiberglas (ECC-127)	.044"	1082	65	Table VIIa
Nylon Belting	.041"	1053	65	Table V
Fiberglas (ECC-113)	.044"	1101	66	Table VIIa
Fiberglas (ECC-128)	.044"	1090	66	Table VIIa
Fiberglas (ECC-138)	.044"	1108	67	Table VIIa
21 plies Fiberglas (ECC-162) plus 1 ply sized 17½ oz. Nylon Duck with 8" quilting	.045"	1130	67	Table VI
Nylon Belting	.040"	1075**	67	Table V
Nylon Belting	.041"	1085**	67	Table V
21 plies Fiberglas (ECC-162) plus 1 ply sized 17½ ounce Nylon Duck with ½-inch quilting	.045"	1138	68	Table VI
Fiberglas (ECC-135)	.044"	1134	68	Table VIIa
21 plies Fiberglas (ECC-162) plus 1 ply sized 17½ oz. Nylon Duck with 4" quilting	.045"	1148	69	Table VI

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TABLE XII (CONT'D)

Material	Equiv. Steel Gauge	Cal. .22 Ballistic Limit	Cal. .22 Figure of Merit*	Reference
Weinberger Protective Fabric	.040"	1108	69	Table X
21 plies Fiberglas (ECO-162) plus 1 ply sized 17½ oz. Nylon Duck with 1" quilting	.045"	1173	70	Table VI
23 plies Fiberglas (ECO-162) with 2" quilting	.045"	1189**	71	Table VI
23 plies Fiberglas (ECO-162) plus 1 ply sized 17½ oz. Nylon Duck with 2" quilting	.049"	1238**	71	Table VI
17 plies Fiberglas (ECO-162) plus 3 plies sized 17½ oz. Nylon Duck with 2" quilting	.045"	1208	72	Table VI
Fiberglas (ECO-161)	.044"	1188	72	Table VIIa
23 plies Fiberglas (ECO-162) plus 1 ply sized 17½ oz. Nylon Duck with 2" quilting	.049"	1290	74	Table VI
13 plies unsized 19 ounce Nylon Duck	.043"	1309	80	Table III
14 plies unsized 19 ounce Nylon Duck	.046"	1350	80	Table III
12 plies unsized 19 ounce Nylon Duck	.039"	1283	81	Table III
11 plies sized 17½ ounce Nylon Duck	.040"	1310	82	Table III
12 plies sized 17½ ounce Nylon Duck	.044"	1360	82	Table III
Silk Webbing	.042"	1336	82	Table IX
Nylon Parachute Cloth	.044"	1370	83	Table IVa
11 plies sized 17½ oz. Nylon Duck	.040"	1360**	85	Table X
Nylon Parachute Cloth	.044"	1435	86	Table IVa
Nylon Parachute Cloth	.044"	1435	86	Table IVa
Nylon Parachute Cloth	.045"	[illegible]	88	Table X

*Figure of Merit determined from the formula: $\frac{V_{SUB} \times 100}{V_{HAD}}$, where V_{SUB} is the ballistic limit of the subject sample and V_{HAD} the characteristic ballistic limit of an equivalent weight of Hadfield manganese steel.

**As strapped to a sawdust-filled canvas dummy.

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TABLE XIII

Average Figures of Merit for Various Fabrics

With Respect to Their Perforation by Cal. .45 Ball Projectiles

Material	Average Figure of Merit
Nylon Duck - Sized	79
Fiberglas (ECC-135)	79
Silk Webbing	79
Nylon Parachute Cloth	73
Nylon Duck - Unsized	72
Weinberger Protective Fabric - Quilted Element	69
Weinberger Protective Fabric - Complete	62
Nylon Belting	58
Weinberger Protective Fabric - Corded Element	56
Cotton Duck	43

APPENDIX D

TABLE XIV

Average Figures of Merit for Various Fabrics

With Respect to Their Perforation by Cal. .22

Fragment-Simulating Projectiles, F-2

Material	Average Figure of Merit
Nylon Parachute Cloth	85
Nylon Duck - Sized	82
Silk Webbing	82
Nylon Duck - Unsized	80
Fiberglas (ECC-161)	72
Weinberger Protective Fabric - Complete	69
Nylon Belting	63
Weinberger Protective Fabric - Corded Element	62
Weinberger Protective Fabric - Rubber-coated Corded Element	61
Cotton Duck	52

APPENDIX E

PLASTIC LAMINATES

References

(Applicable to APPENDIX E)

1. O.O. 422.3/71 - Wtn. 470.5/7443. 28 September 1943.

2. O.O. 422.3/100 - Wtn. 422/9. 10 November 1943.

3. O.O. 422.3/122 - Wtn. 422/12. 27 November 1943.

4. O.O. 470.5/5262 - Wtn. 470.5/7898. 9 February 1944.

5. O.O. 400.112/13942 - Wtn. 400.112/3134. 19 June 1944.

6. O.O. 470.1/476 - Wtn. 470.1/7254. 13 July 1944.

7. O.O. 400.112/14862 - Wtn. 400.112/3. 29 July 1944.

8. O.O. 400.112/15010 - Wtn. 400.112/3167. 7 August 1944.

9. BTE 160/3954/47482 - Wtn. 400.112/3722. 14 December 1944.

10. Report No. WAL 710/261. "Resistance of K Panels Submitted by the U. S. Rubber Company to Perforation by Fragment-Simulating Projectiles." J. F. Sullivan. 3 January 1945.

11. Report No. WAL 710/264. "Resistance of Various Laminates Supplied by U. S. Rubber Co. to Perforation by Cal. .45 Steel-Jacketed Ball Projectiles." J. F. Sullivan. 16 October 1944.

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13. Report No. WAL 710/317. "Resistance of Samples of Laminates Submitted by Victory Plastics Company to Perforation by Fragment-Simulating Projectile, G-1-S. J. F. Sullivan. 23 October 1944.

14. Report No. WAL 710/568. "Ballistic Characteristics of Various Samples of Experimental Body Armor Materials." J. F. Sullivan. 17 December 1943.

15. Report No. WAL 710/641. "Resistance of Various Samples of Plastics Materials to Perforation by Fragment-Simulating Projectiles." J. F. Sullivan. 25 May 1944.

16. Report No. WAL 710/689. "Resistance of Various Types of Laminates Supplied by U. S. Rubber Co. to Perforation by Flak-Simulating Projectiles." J. F. Sullivan. 21 August 1944.

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(Applicable to APPENDIX E)

17. Report No. WAL 710/699. "Effects of High Temperature (+175°F.) and Low Temperature (-65°F.) upon the Resistance of Doron (Type #1) to Perforation by Flak-Simulating Projectiles." J. F. Sullivan. 4 October 1944.

18. Report No. WAL 710/732. "Resistance of Various Plastic Laminates, Made by Victory Plastics Co., to Perforation by Fragment-Simulating Projectiles." J. F. Sullivan. 22 March 1945.

19. Report No. WAL 762/247. "Development of Projectiles to Be Used in Testing Body Armor, to Simulate Flak and 20 mm. HE Fragments." J. F. Sullivan. 17 December 1943.

20. Report No. WAL 762/253. "Development of a Projectile, to Be Used in Testing Body Armor, to Simulate Fragments of a 20 mm. HE Projectile." J. F. Sullivan. 7 January 1944.

21. Report No. WAL 762/314. "Comparison of G-2 Projectiles of Various Manufacture." J. F. Sullivan. 23 May 1945.

APPENDIX E

TABLE I

(Reference - Report No. WAL 710/641)

Summary of Ballistic Tests Conducted at Watertown Arsenal on Various Plastic Materials (Doron) Submitted by Quartermaster Corp.

Quartermaster Identification	Equivalent Steel Gauge	Ballistic Limits (F/S) Caliber .45[1] Room Temp.	-60°F.	After Immersion	Room Temperature C-1-A[2]	C-1-B[3]	C-2[4]
R-141	.029"	895	-	-	340	760	1161
R-404d	.040"	1041	-	-	475	901	1380
R-404j	.041"	1037	-	1006	435	906	1460
R-158	.041"	-	-	-	508	910	-
R-148	.041"	1105	-	-	495	1009	1478
R-166	.042"	984	-	-	488	973	1283
R-150	.042"	974	-	-	513	1043	1370
R-147	.042"	1060	-	-	475	1030	-
R-117	.043"	1104	-	-	483	1030	-
R-159	.044"	1105	-	-	453	955	-
R-116	.045"	1152	-	-	493	1065	1293
R-124	.045"	1117	1124	-	560	975	1443
R-123	.046"	1098	1123	-	532	955	1430
R-120	.046"	1162	1173	-	468	1165	-
R-113	.047"	1104	1118	-	445	998	1345
For Comparison:							
Hadfield	.030"	704	-	-	-	815	1215
Manganese	.040"	900	-	-	-	900	1500
Steel	.045"	950	-	-	-	1050	1675

1. Caliber .45 (steel-jacketed) ball projectile - 230 grains.

2. Caliber .30 fragment-simulating projectile - 150 grains.

3. Caliber .30 fragment-simulating projectile - 54 grains.

4. Caliber .22 fragment-simulating projectile - 17 grains.

APPENDIX E

TABLE II

(Reference - Report No. WAL 710/699)

Summary of Ballistic Tests Conducted at Watertown Arsenal on Samples of Doron (Type #1) Which Had Previously Been Subjected to Direct 20 mm. H.E. Fragmentation Tests at Aberdeen Proving Ground

Sample	Ballistic Limit (F/S) Cal. .45	G-2
(Samples fired at room temperature, as-received):		
R474G	1011	1348
R474F	1010	1350
R474L	973	1344
R474O	909	1344
R474N	1035	1404
R474K	1039	1378
R474E	1041	1408
R580A	1060	1346
R575A	1015	1279
R582C	1014	1373
(Samples fired at -65° at end of 4th phase of weathering cycle):		
R573A	1030	-
R582F	1021	-
R580C	1031	-
R583A	-	1363
R577E	-	1460
R579C	-	1344
R575D	-	1285
(Samples fired at room temperature at end of 4th phase of weathering cycle):		
R579C	1065	-
R572B	1117	-
R579D	1175	-
(Samples fired at +175° F. at end of 5th phase of weathering cycle):		
R583A	1057	-
R574B	1096	-
R574D	1060	-
R578B	-	1270
R579D	-	1415
R574	-	1285
R574B	-	1257
R576B	-	1407
(Samples fired at room temperature at end of 5th phase of weathering cycle):		
R577D	1038	-
R577E	1072	-
R574	1046	-
(Samples fired at +175°F. after a hot phase of the weathering cycle during which temperature of cabinet rose above 200°F. for a period of several hours).		
R575E	680	-
R577D	869	-
R583D	836	-
R573A	680	-
R582F	676	-
R574E	805	-

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TABLE III

(Reference - Report No. WAL 710/264)

Summary of Tests for Resistance to Perforation Conducted
at Watertown Arsenal on Laminates Developed by U. S. Rubber Co.

Sample No.	Type	Weight (Grams)	Weight/Sq.Ft. (Grams)	Thick-ness	Equivalent Steel Gauge	Ballistic Limit Cal. .45*
1	Nylon-Rubber	1553	1141	15/32"	.062"	606 ± 15
2	Nylon-Rubber	1129	830	11/32"	.045"	569 ± 22
3	Fiberglas-Resin	918	675	3/16"	.036"	425 ± 25
4	Fiberglas-Resin	1093	803	7/32"	.043"	445 ± 50
5	Nylon-Resin	983	723	11/32"	.039"	367 ± 67
For Comparison:						
Doron		-	-	—	.040"	1050
Hadfield Manganese		-	-	—	.040"	900

*Cal. .45 steel-jacketed ball projectile (230 grains).

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TABLE IV

(Reference - Report No. WAL 710/689)

Summary of Resistance to Perforation Tests Conducted at Watertown Arsenal on

Samples of Laminates Supplied by U. S. Rubber Co.

Sample No.	Type	Broad	Filler	Weight (oz./sq.ft.)	Thick-ness	Equiv. Steel Gauge	Cal. .45[1]	G-22
1	3-decker	8-ply nylon & resin	1/8" cellular rubber	19.7	7/16"	.030"	465	-
2	3-decker	8-ply nylon & resin	.020" neoprene	17.2	5/32"	.026"	460	-
3	3-decker	8-ply fiberglas & resin	1/8" cellular rubber	21.0	13/32"	.032"	447	-
4	3-decker	8-ply fiberglas & resin	.020" neoprene	19.7	3/16"	.030"	416	840
5	3-decker	8-ply nylon & resin	21-ply nylon cured rubber	26.3	1/4"	.040"	395	725
6	3-decker	8-ply fiberglas & resin	21-ply nylon cured rubber	26.2	1/4"	.040"	428	670
7	3-decker	8-ply nylon & resin	rayon pile	14.7	3/8"	.023"	432	-
8	3-decker	8-ply nylon & resin	nylon pile	17.1	1/2"	.026"	449	-
9	single	8-ply nylon & resin	none	3.7	3/128"	.006"		not
10	single	15-ply nylon & resin	none	6.6	5/64"	.010"		fired
11	single	8-ply fiberglas & resin	none	4.3	1/32"	.007"		because of
12	single	21-ply nylon & rubber	none	6.0	1/16"	.009"		lightness

1. Cal. .45 steel-jacketed ball projectile - 230 grains.

2. Cal. .22 fragment-simulating projectile - 17 grains.

Table [illegible]

Summary of Ballistic Tests [illegible] on Samples of Plastic Laminates

Submitted by [illegible] Plastics Co.

(Reference - Report No. [illegible] 710/732)

Sample No.	Make-Up of Sample	Sample Size	Sample Weight (Grams)	Equiv. Steel Gauge	Ballistic Limit Cal. .45[1] Req.	Cal. .45[1] Act.	G-1-S[2] Req.	G-1-S[2] Act.	G-2[3] Req.	G-2[3] Act.
[illegible]	11 ply Fiberglass ECC-11-164 coated with 6B [illegible]. 12 Ply Hi/ten Rayon 2 oz. Alternate layers. Coated with 6B Nylon solution, molded at 1500 lbs. per sq. in. for 15 min. at 320 F.	2-3/4"x2-3/4"	26.0	.029"	—	—	760	<975	—	—
[illegible]	14 ply Fiberglass ECC-11-164 coated with 6B Nylon. 14 ply Nylon 6 oz. alternate layers, coated with 6B Nylon, molding pressure 1500 lbs. per sq. in. for 45 min. at 320 F.	2-3/4"x2-3/4"	46.0	.047"	—	—	1120	<860	—	—
[illegible]	14 ply Fiberglass ECC-11-164 coated with 6B Nylon. 14 ply Hi/ten Rayon 2 oz. alternate layers coated with 6B Nylon, molding pressure 1500 lbs. per. sq. in. for 30 min. at 320 F.	2-3/4"x2-3/4"	33.0	.034"	—	—	860	775±70	—	—
[illegible]	15 ply Fiberglass ECC-11-164 coated with 6B Nylon. 8 ply Hi/ten Rayon 2 oz. alternate layers in back of sample, coated with 6B Nylon. Molding pressure 1500 lbs. per. sq. in. for 30 min. at 310 F.	3"x3"	48.0	.041"	—	—	1000	<865	—	—
[illegible]	13 ply Fiberglass ECC-11-164 coated with 6B Nylon. 6 ply Nylon 6 oz. alternate layers in back portion of sample. Coated with 6B Nylon, molding pressure 1500 lbs. per sq. in. for 30 min. at 320 F.	3"x3"	47.0	.041"	—	—	1000	<855	—	—
[illegible]	15 ply Fiberglass ECC-11-164 coated with 6B Nylon. 8 ply Hi/ten Rayon 2 oz. alternate layers in back portion of sample. Coated with 6B Nylon, molding pressure 1000 lbs. per sq. in. for 30 min. at 320 F.	3"x3"	46.0	.040"	—	—	960	<845	—	—
1025[illegible]	14 ply Fiberglass ECC-11-164. Both fabrics coated with Gelva 15. 14 ply Nylon 6 oz. alternate layers. Molding pressure 200 lbs. per sq. in. for 30 min. at 320 F.	3"x3"	65.0	.056"	—	—	1300	<915	—	—
[illegible]	14 ply Fiberglass ECC-11-164. Both fabrics coated with Gelva-15. 14 ply H/ten Rayon 2 oz. alternate layers. Molding pressure 200 lbs. per sq. in. for 30 min. at 320 F.	3"x3"	47.0	.041"	—	—	1000	890±50	—	—
1025[illegible]	14 ply Fiberglass ECC-11-164. Both fabrics coated with Gelva-15. 14 ply Hi/ten Rayon 2 oz. alternate layers. Molding pressure 100 lbs. per sq. in. for 30 min. at 320 F.	3"x3"	47.0	.041"	—	—	1000	840 App.	—	—
[illegible]	14 ply Fiberglass ECC-11-164. Heated in oven 2 hrs. at 400 F. and coated with 6B Nylon. Molding pressure 300 lbs. per sq. in. for 30 min. at 320 F.	2-3/4"x2-3/4"	32.0	.033"	—	—	810	<840	—	—
[illegible]	Same as 1027[illegible] except the Fiberglass was not heat treated and the molding pressure reduced to 150 lbs. per sq. in.	3"x3"	39.0	.034"	—	—	660	<785	—	—
1027[illegible]	Same as 1027[illegible] except the molding pressure was reduced to 125 lbs. per sq. in.	3"x3"	38.5	.033"	—	—	840	<790	—	—
[illegible]	[illegible]	[illegible]	[illegible]	.033"	—	—	840	<780	—	—

sq. in. for 30 min. at 320 F.

1025##B	14 ply Fiberglass ECC-11-164. Both fabrics coated with Galva-15. 14 ply Hi/ten Rayon 2 sq. alternate layers. Molding pressure 100 lbs. per sq. in. for 30 min. at 320 F.	3"x3"	47.0	.041"	--	--	1000	840 App.	--	--
1027##A	14 ply Fiberglass ECC-11-164. Heated in oven 2 hrs. at 400 F. and coated with 68 Nylon. Molding pressure 300 lbs. per sq. in. for 30 min. at 320 F.	2-3/4"x2-3/4"	32.0	.035"	—	—	840	<840	—	—
1027##B	Same as 1027##A except the Fiberglass was not heat treated and the molding pressure reduced to 150 lbs. per sq. in.	3"x3"	39.0	.034"	—	—	660	<765	—	—
1027##C	Same as 1027##B except the molding pressure was reduced to 125 lbs. per sq. in.	3"x3"	38.5	.033"	—	—	840	<790	—	—
1027##D	Same as 1027##B and C except the molding pressure was increased to 200 lbs. per sq. in.	3"x3"	38.0	.033"	--	—	840	<780	—	—
1027##E	14 ply Fiberglass ECC-11-164. No heat treatment. 14 ply Vinylite (0.004") alternate layers, molding pressure 200 lbs. per sq. in. for 30 min. at 320 F.	3"x3"	44.0	.038"	--	—	940	845±35	—	—
1027##F	Same as 1027##E except the molding pressure was reduced to 150 lbs. per sq. in.	3"x3"	43.0	.037"	—	—	920	863±18	—	—
1031##A	17 ply Fiberglass X-1551. 17 ply Vinylite (0.004") alternate layers, molding pressure 500 lbs. per sq. in. for 30 min. at 320 F.	7-1/2"x7-1/2"	261	.036"	930	>899	—	—	—	—
1031##B	Same as 1031##A except molding pressure was reduced to 250 lbs. per sq. in.	7-1/2"x7-3/8"	256	.035"	910	804±24	—	—	—	—
1031##C	3 ply Duck (0.080"). 4 ply Tenite II H3, alternate layers, molding pressure 500 lbs. per sq. in. for 15 min. at 320 F.	7-1/2"x7-1/2"	334	.046"	1050	<512	—	—	—	—
1031##F	5 ply Duck (0.080"). 5 ply Vinylite alternate layers, molding pressure 500 lbs. per sq. in. for 30 min. at 320 F. (0.004").	7-1/2"x7-1/2"	--	.042"	1000	<514	—	—	—	—
1031##G	Same as 1031##F except 3 plys of each were used in place of alternate layers of 5 each.	7-3/8"x7-1/2"	269	.037"	950	<509	—	—	—	—
1113##A	25 ply Fiberglass X-1551. 25 Vinylite (0.004") alternate layers, molding pressure 650 lbs. per sq. in. for 30 min. at 320 F.	7.6"x7.6"	385	.052"	1130	1108	—	—	—	—
1113##B	22 ply Fiberglass X-1551. 22 ply Vinylite (0.004") alternate layers. Molding pressure 500 lbs. per sq. in. for 30 min. at 320 F.	7.5"x7.6"	350	.047"	1065	1000	—	—	—	—
1114##A	21 ply Fiberglass ECC-128-38. 21 ply Butvar (0.015") alternate layers. Molding pressure 650 lbs. per sq. in. for 15 min. at 330 F.	5"x5"	168	.052"	1130	<1105	—	—	—	—
1115##A	40 ply Fiberglass ECC-128-38 coated with 10% [illegible] P. V. Butyral on both sides. Penetration complete. Molding pressure 500 lbs. per sq. in. for 30 min. at 275 F.	6"x6"	590	.043"	--	—	—	—	1430	1272±63
1115##B	23 ply Fiberglass ECC-128-38. 23 ply Saran screen (Velon), alternate layers. Molding pressure 500 lbs. per sq. in. for 35 min. at 340 F.	6"x6"	352	.043"	—	—	—	—	1410	<1025
1125##A	34 ply Fiberglass ECC-128-38. 2 ply Styron (S.V.) alternate plys of styron between the 17th and 19th ply of Fiberglass. Molding pressure 900 lbs. per sq. in. for 30 min. at 270 F.	6"x6"	283	.034"	—	—	—	--	2170	952±48
1125##B	30 ply Fiberglass ECC-128-38. 2 ply Emery cloth No. 40. 21 ply Butvar (0.015"). Emery cloth placed in alternate layers starting with the 15th ply of Butvar and Fiberglass. Molding pressure 250 lbs. per sq. in. for 30 min. at 280 F.	7"x7"	406	.064"	—	—	—	—	1830	1360
		[illegible]	759	.044"	1030	[illegible]	—	—	—	—

	... lbs. per sq. in. for 30 min. at 340 F.									
[illegible]	[illegible] ply Fiberglass ECC-128-38. 2 ply Styron (S.V.) alternate plys of styron between the 17th and 19th ply of Fiberglass. Molding pressure 500 lbs. per sq. in. for 30 min. at 270 F.	8"x8"	283	.034"	—	—	—	—	2130	952±48
11[illegible]	20 ply Fiberglass ECC-128-38. 2 ply Emery cloth No. 40. 21 ply Butvar (0.015"). Emery cloth placed in alternate layers starting [illegible] the 17th ply of Butvar and Fiberglass. Molding pressure 250 lbs. per sq. in. for 30 min. at 280 F.	7"x7"	406	.064"	—	—	—	—	1630	1360
[illegible]	[illegible] ply X-1951 Fiberglass coated with a Vinyl [illegible]. Molding pressure 500 lbs. per sq. in. for 10 min. at 340 F.	8"x8"	359	.044"	1030	>958	—	—	—	—
11545B	15 ply X-1951 Fiberglass coated with a Vinyl dispersion. 7 ply Rayon coated with a Vinyl dispersion-alternate layers in center portion of sample; molding pressure 250 lbs. per sq. in. for 5 min. at 340 F.	8"x8"	359	.044"	1030	<828	—	—	—	—
[illegible]	15 ply X-1951 Fiberglass coated with Vinyl dispersion. 9 ply Butvar (0.005") alternate layers in center portion of sample; molding pressure [illegible] lbs. per sq. in. for 10 min. at 340 F.	8"x8"	353	.043"	1015	<875	—	—	—	—
115[illegible]	Same as 115[illegible] except the molding pressure was reduced to [illegible] lbs. per sq. in. for 5 min. at 340 F.	8"x8"	375	.046"	1030	824±23	—	—	—	—
115[illegible]	20 ply X-1951 Fiberglass - no coating. 19 ply Butvar (0.005") alternate layers; molding pressure 100 lbs. per sq. in. for 5 min. at 340 F.	8"x8"	332	.040"	990	<809	—	—	—	—
12[illegible]-1	22 ply X-1951 Fiberglass, coated with Vinyl dispersion. Molding pressure 650 lbs. per sq. in. for 15 min. at 340 F.	12"x11-1/2"	845	.046"	1075	860 Face 875 Rear	—	—	—	—
[illegible]	" " " "	12"x12"	872	.047"	1065	820	—	—	—	—
[illegible]	" " " "	12"x12"	890	.046"	1075	821	—	—	—	—
[illegible]	Same as 12405A except molding pressure was increased to 800 lbs. per sq. in.	12"x12"	875	.047"	1065	802	—	—	—	—
[illegible]	" " " "	12"x12"	894	.045"	1075	848	—	—	—	—
[illegible]	" " " "	12"x12"	893	.045"	1075	817	—	—	—	—
[illegible]	Same as 12405A and B except molding pressure was increased to 1000 lbs. per sq. in.	12"x12"	887	.045"	1075	827	—	—	—	—
[illegible]	" " " "	12"x12"	895	.046"	1075	852	—	—	—	—
[illegible]	" " " "	12"x12"	886	.046"	1075	819	—	—	—	—
[illegible]	" " " "	12"x12"	891	.046"	1075	839	—	—	—	—
[illegible]	" " " "	12"x12"	852	.045"	1075	812	—	—	—	—
[illegible]	" " " "	12"x12"	876	.047"	1065	817	—	—	—	—

[illegible] Steel-jacketed ball projectile - 230 grains

[illegible] Cal. .30 Fragment-simulating projectile - 34 grains

Cal. .22 Fragment-simulating projectile - 17 grains

APPENDIX E

TABLE VI

(Reference - Report No. WAL 710/317)

Summary of Tests Conducted at Watertown Arsenal on Samples of Laminates

Submitted by Victory Plastics Company, 20 October 1944

Sample No.	Company No.	Make-Up	Weight (Grams)	Size	Equiv. Steel Gauge	Results with Projectile G-1-S[1]: High Complete Perforation	Low Partial Perforation	Ballistic Limit
I	101944A	11 plies 2 oz. rayon alternated with 11 plies fiberglas.	28	2-3/4 x 2-3/4"	.029"	975	-	975
II	102044A	14 plies 2 oz. rayon alternated with 14 plies fiberglas.	33	2-3/4 x 2-3/4"	.034"	845	705	775 ± 70
III	101944B	11 plies 6 oz. nylon alternated with 11 plies fiberglas.	46	2-3/4 x 2-3/4"	.047"	860	-	860
FOR COMPARISON:								
Doron					.029"	-	-	760
"					.034"	-	-	860
"					.047"	-	-	1095

1. Cal. .30 fragment-simulating projectile - 34 grains.

APPENDIX E

TABLE VII

(Reference - Report No. WAL 710/281)

Summary of Ballistic Tests Conducted at Watertown Arsenal on Samples of "K Panels" Submitted by the U. S. Rubber Company

July Shipment

Name	Make-Up	Lbs. Sq.Ft.	Equiv. Steel Gauge	Ballistic Limits Cal. .45[1]	Ballistic Limits .22[2]
K Panel	.051" - .062" - .062"	1.93	.047"	[illegible]	—
K Panel	.051" - .062" - .062"	1.89	.046"	—	[illegible]
K Panel	.051" - .062" - .062"	1.89	.046"	—	1350
K Panel	.051" - .062" - .062"	1.89	.046"	[illegible]	—
K Panel	.040" - .062" - .062"	1.79	.044"	[illegible]	—
K Panel	.040" - .062" - .062"	1.84	.045"	—	[illegible]
K Panel	.064" - .051" - .051"	1.86	.046"	865	—
K Panel	.064" - .051" - .051"	2.00	.049"	779	—
K Panel	.064" - .051" - .051"	2.00	.049"	—	[illegible]
K Panel	.064" - .051" - .051"	2.10	.051"	—	[illegible]
K Panel	.072" - .051" - .051"	2.20	.054"	[illegible]	—
K Panel	.072" - .051" - .051"	2.10	.052"	793	—
K Panel	.072" - .051" - .051"	1.85	.045"	—	[illegible]
K Panel	.072" - .051" - .051"	2.10	.051"	—	[illegible]
K Panel	.125" - .051" - .051"	2.83	.069"	[illegible]	—
K Panel	.125" - .051" - .051"	2.83	.069"	—	[illegible]
For Comparison:					
Hadfield Manganese Steel	—	—	.045"	950	[illegible]

1. Cal. .45 steel-jacketed ball projectile - 230 grains.

2. Cal. .22 fragment-simulating projectile - 17 grains.

APPENDIX E

TABLE VIII

(Reference - Report No. WAL 710/286)

Summary of Ballistic Tests Conducted at Watertown Arsenal on

Samples of "K Panels" Submitted by U. S. Rubber Co.

Nominal Make-Up		Ave. Gross Thick.	Weight (Grams)	Weight Sq.Ft.	Equiv. Steel Thick.	Ballistic Limits Cal. .45[1]	Ballistic Limits .22[2]
.125"-.051"-.051"	A	.262"	1842	1354	.073"	—	1463
	B	.260"	1820	1338	.072"	—	1405
	C	.266"	1844	1355	.073"	—	1570
	D	.265"	1841	1353	.073"	—	1440
	F	.264"	1835	1349	.073"	871	—
	G	.255"	1815	1334	.072"	937	—
	H	.256"	1811	1331	.072"	940	—
	I	.259"	1855	1363	[illegible]	980	—
.072"-.051"-.051"	A	.226"	1333	980	.053"	—	1320
	B	.203"	1328	976	.053"	—	1328
	C	.213"	1363	1002	.054"	—	1365
	D	.207"	1329	977	.053"	—	1358
	E	.205"	1334	980	.053"	—	1323
	F	.203"	1335	981	.053"	757	—
	G	.198"	1326	975	.053"	770	—
	H	.204"	1342	986	.053"	725	—
	I	.210"	1370	1007	.054"	802	—
	J	.211"	1305	959	.052"	[illegible]	—
.064"-.051"-.051"	A	.199"	1270	933	.050"	—	1170
	B	.197"	1287	[illegible]	.051"	—	1203
	C	.207"	1312	964	.052"	—	1208
	D	.204"	1309	962	.052"	—	1302
	E	.206"	1260	926	.050"	—	1318
	F	.199"	1265	930	.050"	798	—
	G	.202"	1305	959	.052"	702	—
	H	[illegible]	1273	936	.051"	718	—
	I	.193"	1308	961	.052"	771	—
	J	.201"	1273	936	.051"	683	—
.051"-.064"-.064"	A	.208"	1252	920	.050"	—	1263
	B	.193"	1242	913	.049"	—	1167
	C	.204"	1258	925	.050"	—	1330
	D	.213"	1240	911	.049"	—	1255
	E	.207"	1199	881	.048"	—	1093
	F	.200"	1233	906	.049"	730	—
	G	.201"	1232	906	.049"	723	—
	H	.200"	1242	913	.049"	721	—
	I	.208"	1240	911	.049"	740	—
	J	.199"	1197	880	.048"	778	—
.040"-.064"-.064"	A	.193"	1140	838	.045"	—	1143
	B	.190"	1145	842	.042"	—	1175
	C	.192"	1176	864	.047"	—	1195
	D	.190"	1126	828	.045"	—	1128
	E	.202"	1135	834	.045"	--	1128
	F	.185"	1148	844	.046"	621	—
	G	.192"	1168	858	.046"	715	—
	H	.193"	1173	862	.047"	[illegible]	—
	I	.197"	1113	[illegible]	.044"	650	—
	J	.190"	1125	827	.045"	655	—
For Comparison:							
Hadfield Manganese Steel		-	—	-	.045"	950	1675

1. Cal. .45 steel-jacketed ball projectile - 230 grains.
2. Cal. .22 fragment-simulating projectile - 17 grains.

APPENDIX E

TABLE IX

Comparative Resistance of Various Samples of Laminates to Perforation by Cal. .45 Ball Projectiles

Material	Equiv. Steel Gauge	Cal. .45 Ballistic Limit	Cal. .45 Figure of Merit*	Reference
Nylon-Resin Combination	.039"	367	41	Table III
3-Decker, 8-ply Nylon-Resin with 21-ply Nylon Cured Rubber Filler	.040"	395	44	Table IV
Fiberglas-Resin Combination	.043"	445	47	Table III
3-Decker, 8-ply Fiberglas-Resin with 21-ply Nylon Cured Rubber Filler	.040"	428	46	Table IV
3-ply Duck (.080"), 4-ply Tenite #H5, alternate layers	.046"	512	53	Table V
5-ply Duck (.080"), 5-ply Vinylite, alternate layers	.042"	514	56	Table V
Nylon-Rubber Combination	.045"	569	60	Table III
"K" Panel .040" - .064" - .064"	.046"	621	65	Table VIII
"K" Panel .064" - .051" - .051"	.051"	683	68	Table VIII
"K" Panel .040" - .064" - .064"	.044"	650	69	Table VIII
"K" Panel .040" - .064" - .064"	.045"	655	69	Table VIII
"K" Panel .040" - .064" - .064"	.047"	686	71	Table VIII
"K" Panel .064" - .051" - .051"	.051"	716	71	Table VIII
"K" Panel .051" - .064" - .064"	.049"	723	73	Table VIII
"K" Panel .051" - .064" - .064"	.049"	721	73	Table VIII
"K" Panel .051" - .064" - .064"	.049"	730	74	Table VIII
"K" Panel .040" - .064" - .064"	.046"	715	74	Table VIII
"K" Panel .051" - .064" - .064"	.049"	740	75	Table VIII
"K" Panel .064" - .051" - .051"	.049"	779	79	Table VII
"K" Panel .072" - .051" - .051"	.051"	793	79	Table VII
"K" Panel .051" - .064" - .064"	.048"	778	79	Table VIII
"K" Panel .064" - .051" - .051"	.050"	798	80	Table VIII
22-ply X1551 Fiberglas, coated with Vinyl dispersion, molding pressure 800 p.s.i.	.047"	801	83	Table V

TABLE IX (CONT'D)

Material	Equiv. Steel Gauge	Cal. .45 Ballistic Limit	Cal. .45 Figure of Merit*	Reference
22-ply X1551 Fiberglas, coated with Vinyl dispersion, molding pressure 800 p.s.i.	.048"	817	83	Table V
22-ply X1551 Fiberglas, coated with Vinyl dispersion, molding pressure 1000 p.s.i.	.048"	812	83	Table V
22-ply X1551 Fiberglas, coated with Vinyl dispersion, molding pressure 1000 p.s.i.	.048"	827	84	Table V
22-ply X1551 Fiberglas, coated with Vinyl dispersion, molding pressure 1000 p.s.i.	.048"	819	84	Table V
22-ply X1551 Fiberglas, coated with Vinyl dispersion, molding pressure 1000 p.s.i.	.047"	817	84	Table V
22-ply X1551 Fiberglas, coated with Vinyl dispersion, molding pressure 650 p.s.i.	.048"	821	84	Table V
22-ply X1551 Fiberglas, coated with Vinyl dispersion, molding pressure 650 p.s.i.	.047"	820	85	Table V
22-ply X1551 Fiberglas, coated with Vinyl dispersion, molding pressure 1000 p.s.i.	.048"	839	86	Table V
22-ply X1551 Fiberglas, coated with Vinyl dispersion, molding pressure 100 p.s.i.	.046"	824	86	Table V
"K" Panel .051" - .062" - .062"	.046"	824	86	Table VII
22-ply X1551 Fiberglas, coated with Vinyl dispersion, molding pressure 800 p.s.i.	.048"	848	87	Table V
22-ply X1551 Fiberglas, coated with Vinyl dispersion, molding pressure 1000 p.s.i.	.048"	862	88	Table V
22-ply X1551 Fiberglas, coated with Vinyl dispersion, molding pressure 650 p.s.i.	.048"	860	88	Table V
15-ply X1551 Fiberglas coated with Vinyl dispersion; 7-ply Rayon coated with Vinyl dispersion, alternate layers in center portion; 250 p.s.i.	.044"	828	88	Table V
19-ply X1551 Fiberglas coated with Vinyl dispersion; 9-ply Butvar (.005"); alternate layers in center portion; 250 p.s.i.	.043"	825	89	Table V
20-ply X1551 Fiberglas, no coating; 19-ply Butvar (.005"); alternate layers; 100 p.s.i.	.040"	809	90	Table V
"K" Panel .054" - .051" - .051"	.046"	865	90	Table VII
**"K" Panel .051" - .062" - .062"	.047"	880	91	Table VII
"K" Panel .040" - .062" - .062"	.044"	962	98	Table VII

TABLE IX (CONT'D)

Material	Equiv. Steel Gauge	Cal. .45 Ballistic Limit	Cal. .45 Figure of Merit*	Reference
22-ply X1551 Fiberglas, coated with Vinyl dispersion; 500 p.s.i.	.044"	958	102	Table V
22-ply X1551 Fiberglas, 22-ply Vinylite (.004"); alternate layers; molding pressure 500 p.s.i.	.047"	1030	103	Table V
Doron (Type 1) - R-150	.042"	974	106	Table I
Doron (Type 1) - R-166	.042"	984	107	Table I
Doron (Type 1) - R-113	.047"	1104	114	Table I
Doron (Type 1) - R-123	.046"	1098	114	Table I
Doron (Type 1) - R-4043	.041"	1037	114	Table I
Doron (Type 1) - R-147	.042"	1060	115	Table I
Doron (Type 1) - R-4044	.040"	1041	116	Table I
Doron (Type 1) - R-159	.044"	1105	118	Table I
Doron (Type 1) - R-124	.045"	1117	118	Table I
Doron (Type 1) - R-117	.043"	1104	119	Table I
Doron (Type 1) - R-148	.041"	1105	121	Table I
Doron (Type 1) - R-116	.045"	1152	121	Table I
Doron (Type 1) - R-120	.046"	1162	121	Table I

*Figure of merit determined from the formula: $\frac{V_{SUB} \times 100}{V_{HAD}}$

where V_{SUB} is the ballistic limit of the subject sample and V_{HAD} is the ballistic limit characteristic of samples of Hadfield manganese steel of equivalent weight.

APPENDIX B

TABLE X

Comparative Resistance of Various Samples of Laminates to Perforation by Cal. .22 Fragment-Simulating Projectile, [illegible]-2

Material	Equiv. Steel Gauge	Cal. .22 Ballistic Limit	Cal. .22 Figure of Merit*	Reference
3-Decker: 8-ply Fiberglas-Resin; 21-ply Nylon and Rubber	.040"	670	42	Table IV
3-Decker: 8-ply Nylon-Resin; 21-ply Nylon and Rubber	.040"	725	45	Table IV
23-ply ECC-128 Fiberglas; 23-ply Saran screen (velon); alternate layers; molding pressure 500 p.s.i.	.043"	1025	62	Table V
"K" Panel .051" - .064" - .064"	.048"	1095	64	Table VIII
40-ply ECC-128 Fiberglas coated with 10% T19 P.V. Butyral on both sides, complete penetration; molding pressure 500 p.s.i.	.043"	1078	66	Table V
"K" Panel - .064" - .051" - .051"	.050"	1170	67	Table VIII
"K" Panel - .051" - .064" - .064"	.049"	1167	67	Table VIII
"K" Panel - .040" - .064" - .064"	.045"	1128	67	Table VIII
"K" Panel - .040" - .064" - .064"	.045"	1128	67	Table VIII
"K" Panel - .064" - .051" - .051"	.051"	1205	68	Table VIII
"K" Panel - .040" - .064" - .064"	.045"	1145	68	Table VIII
"K" Panel - .040" - .064" - .064"	.045"	1198	70	Table VIII
"K" Panel - .051" - .064" - .064"	.050"	1263	72	Table VIII
"K" Panel - .051" - .064" - .064"	.049"	1255	72	Table VIII
"K" Panel - .040" - .064" - .064"	.048"	1175	72	Table VIII
"K" Panel - .064" - .051" - .051"	.049"	1287	74	Table VIII
"K" Panel - .064" - .051" - .051"	.050"	1318	75	Table VIII
"K" Panel - .051" - .064" - .064"	.050"	1330	76	Table VIII
Doron (Type 1) - R-116	.045"	1193	77	[illegible]
Doron (Type 1) - R-166	.048"	1283	79	[illegible]
Doron (Type 1) - R-113	.047"	1345	79	[illegible]

APPENDIX E

TABLE X (CONT'D)

Material	Equiv. Steel Gauge	Cal. .22 Ballistic Limit	Cal. .22 Figure of Merit*	Reference
"K" Panel .072" - .051" - .051"	.045"	1327	79	Table VII
"K" Panel .051" - .062" - .062"	.046"	1350	80	Table VII
"K" Panel .040" - .062" - .062"	.045"	1332	80	Table VII
"K" Panel .064" - .051" - .051"	.051"	1408	80	Table VII
"K" Panel .072" - .051" - .051"	.051"	1425	81	Table VII
Doron (Type 1) - R-150	.042"	1370	84	Table I
Doron (Type 1) - R-123	.046"	1430	85	Table I
Doron (Type 1) - R-124	.045"	1443	86	Table I
Doron (Type 1) - R-404d	.040"	1380	86	Table I
"K" Panel .051" - .062" - .062"	.046"	1480	88	Table VII
Doron (Type 1) - R-404J	.041"	1460	90	Table I
Doron (Type 1) - R-148	.041"	1478	92	Table I

*Figure of merit determined from the formula, $\frac{V_{SUB} \times 100}{V_{HAD}}$, where V_{SUB} is the ballistic limit of a subject sample and V_{HAD} is the ballistic limit characteristic of samples of Hadfield manganese steel of equivalent weight.

APPENDIX E

TABLE XI

Average Figures of Merit of Various Classes of Laminates with Respect to Their Resistance to Perforation by Cal. .45 Ball Projectiles

Material	No. Tested	Average Figure of Merit
Doron (Type 1)	13	116
Fiberglas (X1551)	19	87
"K" Panels (Table VII)	6	87
"K" Panels (All)	19	77
"K" Panels (Table VIII)	13	72
Duck	2	55
Rubber Combinations	5	42

APPENDIX E

TABLE XII

Average Figures of Merit of Various Classes of Laminates with Respect to Their Resistance to Perforation by the Cal. .22 Fragment-Simulator, C-2

Material	No. Tested	Average Figure of Merit
Doron (Type 1)	9	84
"K" Panels	20	73
Fiberglas [illegible]-135	2	64
Rubber Combinations	2	44